DETROIT OBSERVATORY

1855

DETROIT OBSERVATORY

PUBLICATIONS

OF THE

ASTRONOMICAL OBSERVATORY

OF THE

UNIVERSITY OF MICHIGAN

VOLUME I

ANN ARBOR:
PUBLISHED BY THE UNIVERSITY
1912

ORGANIZATION OF THE DETROIT OBSERVATORY

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A GENERAL ACCOUNT OF THE OBSERVATORY.

By WILLIAM J. HUSSEY.

HISTORICAL.

The legislative Acts providing for the organization of the University of Michigan were approved on March 18, and June 21, 1837. These Acts contemplated the appointment of a Chancellor of the University, but during the early years of the Institution this office was not filled, the ordinary duties of President being performed in turn by members of the faculty. It was not until the new State Constitution of 1851 was adopted, with its provisions for the reorganization of the University and the betterment of its conditions, that it became mandatory on the part of the Board of Regents to elect a President. They were fortunate in securing Dr. Henry P. Tappan to fill this important post. He was a man of great energy and ability, who looked beyond the narrow horizon of the time, and by well-directed effort, in a few short years, established conditions which have had a great influence on the subsequent history of the University and upon higher education in the West. So important was his work that it may be said that he was the real founder of the University.

Dr. Tappan came to Ann Arbor in October, 1852, and delivered his inaugural address in the following December. On this occasion he presented his policy of making the institution at Ann Arbor a University worthy of the name, and he appealed to the people to take an interest in it and give it their loyal support. At the conclusion of the address, Mr. Henry N. Walker, then a prominent citizen of Detroit, came to him and inquired in what way he could be of service to the University. Dr. Tappan was already planning an expansion of the curriculum by the introduction of engineering and scientific studies, and he at once suggested that Mr. Walker raise funds in Detroit for the establishment of an Astronomical Observatory. A meeting was held there a few days later, for the consideration of the project. Dr. Tappan and others spoke in favor of it, with the result that $7,000 were immediately raised, the Honorable Henry N. Walker, General Lewis Cass, Governor Henry Porter Baldwin, and Senator Z. Chandler, each subscribing $500, on condition that $10,000 be obtained within a year. Mr. Walker took a leading part in raising the funds, which eventually amounted to about $15,000, of which he gave $4,000. In honor of the citizens of Detroit, whose initial gifts made it possible, the Observatory was named "Detroit Observatory." The original building and instruments cost $22,000, of which $7,000 were supplied by the Board of Regents from University funds. Subsequently the citizens of Ann Arbor contributed $2,500 and those of Detroit $3,000, for needed improvements.

In the beginning it was the intention to buy a large telescope only and provide a building for it, but the liberality of the citizens of Detroit soon made it evident that the plan could be enlarged to include what was then regarded as the equipment of a complete Observatory.

When the funds were assured, Dr. Tappan acted upon the advice of his scientific friends and placed an order with Mr. Henry Fitz, of New York, for a refracting telescope, equatorially mounted, of not less than twelve inches aperture, at a cost of $6,000. At that time there were only two larger refractors in the world; namely, two fifteen-inch telescopes, one belonging to the Imperial Russian Observatory, at Pulkowa, and the other to the Harvard College Observatory. The refractor for Ann Arbor was the first large telescope constructed entirely in the United States, a country which has since become noted for the perfection and power of its astronomical instruments.

In March, 1853, while President Tappan was in Europe, mainly in the interest of the Observatory, Mr. Walker, acting in concurrence with him, made arrangements with Mr. George Bird, of New York, to superintend the construction of the Observatory building. Four acres of land, outside the city, on a hill overlooking the valley

of the Huron River, were purchased as a site, at a cost of $100 per acre.

During his trip abroad, President Tappan visited the principal observatories of Europe, and at Berlin had the good fortune to make the acquaintance of Professor Encke, and his young Assistant, Dr. Francis Brünnow. They took great interest in the new observatory and generously gave their counsel as to its equipment. Upon their advice a Meridian Circle was ordered from Pistor and Martins, and an astronomical clock from M. Tiede, both of Berlin. They constantly supervised the construction of these instruments, and when the clock was completed, they tested it thoroughly before it was shipped to the United States.

More important than the instruments which President Tappan obtained in Germany was the man whom he found in Berlin and persuaded to come to America to be the first Director of the Observatory. To this circumstance, more than to any other, is due the early fame of the Observatory and the wide influence which it has had on the development of Astronomy in the United States. When Dr. Francis Brünnow received this appointment he was already widely known, by reason of his numerous contributions to Theoretical and Practical Astronomy, and particularly for his able treatise on *Spherical Astronomy*. During his residence at Ann Arbor he continued his contributions to various astronomical periodicals, issued his tables of the minor planets *Flora* and *Victoria*, and, from 1858 to 1862, published the *Astronomical Notices*, a periodical which was designed as a medium for the prompt publication of the observations and scientific investigations of the officers of this and of other observatories.

Dr. Brünnow arrived in Ann Arbor, in July, 1854, about the time the Observatory building was completed, and within a few months he had installed the Meridian Circle and had begun to use it. There was some delay in getting the refractor in readiness for use. When first set up it was not entirely satisfactory and had to be dismounted to enable the constructor to make some necessary alterations. It was finally re-erected and made ready for use in December, 1857.

Dr. Brünnow was one of the small number of men, who at that early time gave the University its high character for scientific instruction. On his arrival he immediately planned advanced courses in Theoretical and Practical Astronomy, extending over two and a half years, in continuation of the elementary course which was then required of all students in the first semester of the Junior year. Notable among those who elected these advanced courses, soon after they were offered, were Cleveland Abbe, Asaph Hall, Sr., and James C. Watson.

In 1859, Dr. Brünnow accepted the position of Associate Director of the Dudley Observatory, in conjunction with Professor O. M. Mitchell, who, while retaining his position as Director of the Cincinnati Observatory, which he had founded, also assumed the direction of the new institution at Albany. It was the intention that the two observatories should work together in the formation of a large catalogue of stars, and to this end, it was to be Dr. Brünnow's task to bring into immediate activity the new Olcott Meridian Circle of the Dudley Observatory. After a year this work was interrupted, for the Board of Regents then urgently requested Dr. Brünnow to return to Ann Arbor, where he remained until 1863, when he resigned owing to the removal of President Tappan, whose son-in-law he had become. Two years later he became Professor of Astronomy in the University of Dublin and Astronomer Royal of Ireland, where he continued at the Dunsink Observatory his astronomical work, notably his investigations of stellar parallax. On account of failing health he resigned in 1874, and retired, first to Basel, then to Vevey, and finally to Heidelberg, where he died in August, 1891.

In 1863, James Craig Watson was elected Professor of Astronomy and Director of the Observatory. He had graduated at the age of nineteen, in the class of 1857, and in the following year had become Assistant in the Observatory. A year later, when Dr. Brünnow went to Albany, he was made Professor of Astronomy and placed in charge of the Observatory, without being given the title of Director. On Dr. Brünnow's return Professor Watson was transferred to the chair of Physics, a position which he held until Dr. Brünnow resigned. Then, upon his own ap-

plication, supported by the recommendations of B. A. Gould, Elias Loomis, William Chauvenet, Joseph Winlock, Benjamin Pierce, J. M. Gillis, and others, he was made the successor of his eminent teacher. Professor Watson remained at the head of the Observatory until 1879, when he resigned to become the Director of the new Washburn Observatory of the University of Wisconsin, where he died in the following year after an illness of only two days.

Very soon after he became director, Professor Watson began the preparation of a series of charts of the stars situated near the ecliptic, and during his administration this continued the principal observational work of the Observatory. The charts which he prepared, of which only two were completed, so laborious was their preparation by the methods employed, have become the property of the National Academy of Sciences, and are deposited with the Washburn Observatory.

The preparation of these charts was apparently undertaken with the expectation that they would aid in the discovery of additional minor planets, and this proved to be the case. Professor Watson discovered twenty-two of these bodies while he was Director of the Observatory at Ann Arbor. The first one, Eurynome (79), was found on September 14, 1863, only three weeks after he had been elected to this position. Four years passed before a second was detected. Then for a time they came in rapid succession; in 1868 six were added to the list, which was then an unprecedented feat. The complete list is as follows:

Minor Planets Discovered by Professor Watson.

NO.	NAME.	DATE OF DISCOVERY.
79	Eurynome	September 14, 1863
93	Minerva	August 24, 1867
94	Aurora	September 6, 1867
100	Hecate	July 11, 1868
101	Helena	August 15, 1868
103	Hera	September 7, 1868
104	Clymene	September 13, 1868
105	Artemis	September 16, 1868
106	Dione	October 10, 1868
115	Thyra	August 6, 1871
119	Althaea	April 3, 1872
121	Hermione	May 12, 1872
128	Nemesis	November 25, 1872
132	Aethra	June 13, 1873
133	Cyrene	August 16, 1873
139	Juewa	October 10, 1874
150	Nuwa	October 18, 1875
161	Athor	April 16, 1876
168	Sibylla	September 28, 1876
174	Phaedra	September 2, 1877
175	Andromache	October 1, 1877
179	Clytemnestra	November 11, 1877

Juewa (139) was discovered by Professor Watson, at Peking, China, while in charge of an expedition which had been sent there to observe the transit of Venus of 1874. The planet Aethra (132) has been lost. No observations of it have been obtained since the opposition at which it was discovered, 1873, and such observations as were obtained then have not proved sufficient for a satisfactory determination of the elements of its orbit.

The minor planets discovered by Professor Watson are in a sense endowed. He left with the National Academy of Sciences a sum of money for the promotion of astronomical science, and expressed the wish that provision be made for preparing and publishing tables of the motions of the planets which he had found. In compliance with this request the National Academy of Sciences has arranged for the performance of this work, and as a partial result, in 1910, published tables of the motions of twelve of these planets, prepared under the direction of Professor Armin O. Leuschner, of the University of California.

Professor Watson went on several astronomical expeditions, notably on eclipse expeditions to Iowa in 1869, to Sicily in 1870, to Wyoming in 1878, and on the transit of Venus expedition to China in 1874. While returning from China he visited India, Egypt, and Europe. Several weeks were spent in Egypt, where, at the invitation of the Khedive, he coöperated with the engineers of the Egyptian army in the first steps toward a geodetic survey of that country.

The eclipse of 1878 riveted Professor Watson's attention to the Intra-Mercurial problem. He believed in the existence of a major planet between Mercury and the sun; had corresponded with LeVerrier and obtained from him his predicted times of transit of such a body; and at Ann Arbor he had watched the sun in the hope of detecting such a transit. It is a matter of astronomical history that he supposed that he had recorded the place of one and possibly of two major planets at the time of the eclipse of 1878. During the remainder of his life he devoted much

time to preparations which he hoped would enable these supposed planets to be seen without an eclipse. He died suddenly while these preparations were still incomplete. More than thirty years have now passed. The planets have not been recovered, notwithstanding the extensive search made for them by photographic methods during several recent eclipses. Negative results only have been secured, but these have been of such weight that many astronomers have come to entertain grave doubts as to the existence of a large planet within the orbit of Mercury.

Professor Watson published several books, but his fame as an author depends chiefly upon his treatise on *Theoretical Astronomy*, which was prepared during the earlier years of his directorship, while he was devoting much time to the observation of the minor planets and the determination of their orbits. He was endowed in an unusual degree with the mathematical faculty, and seemed to play with problems which taxed the energies of others. He was a computer of remarkable skill and rapidity, as is attested by his making a complete determination of the elliptic elements of a planet's orbit at a single sitting. Early in the '60's he became interested in the reduction of the Washington Zones, which had been undertaken by Dr. Gould, and for several years he devoted much time to the computations of this work. In 1869 he became associated with Professor Benjamin Pierce, of Harvard University, in work designed to improve the lunar tables. For five years he was engaged in the comparison of the theories of Hansen and Pierce with observation, and in endeavors to simplify Hansen's tables, with results which, though satisfactory to himself, were never published and are now lost.

When Professor Watson resigned in 1879, to become the Director of the Washburn Observatory at Madison, Professor Mark W. Harrington was selected to fill the position which his withdrawal made vacant at Ann Arbor. Professor Harrington had graduated with the class of 1868, had been an Astronomical Aid in the reconnaissance work of the United States Coast Survey in Alaska, had filled for a time the Professorship of Astronomy and Mathematics in the Cadet School of the Foreign Office at Peking, China, and had taught various subjects in the University of Michigan.

On taking charge of the Observatory, Professor Harrington arranged for increased facilities for instruction in Practical Astronomy and for regular meteorological observations. The building for the Students' Observatory had been completed in 1879, and in the following year the instrumental equipment was obtained. The chief of these instruments were a six-inch refracting telescope, equatorially mounted, costing $1,800, and a three-inch transit instrument, costing $1,000.

Professor J. M. Schaeberle was at that time an Assistant in the Observatory, and he began to use the Meridian Circle in a new determination of the positions of the Struve double stars. He also undertook other observational work, and in the earlier part of this administration discovered two comets, the first in 1880 and the second in the following year. In 1888, Professor Schaeberle went to California as an Astronomer in the Lick Observatory, and his place as Instructor in Astronomy was filled by the appointment of Professor W. W. Campbell, who had graduated from the University two years earlier, and who followed Professor Schaeberle to the Lick Observatory three years later. While an Instructor in the University of Michigan, Professor Campbell devoted much time to the observation of comets and to the determination of their orbits. It was during this period that his *Elements of Practical Astronomy* was prepared and first printed.

Professor Harrington's tastes had been strongly with the botanical and biological sciences, but on taking charge of the Observatory, he was diverted to other studies, and during his directorship he devoted much time to the consideration of meteorological questions. In 1884, he founded *The American Meteorological Journal*, then the only meteorological periodical published in the United States. In the beginning he was its sole editor, but later several meteorologists were associated with him in its editorial management, notably Professor A. Lawrence Rotch, the founder of the Blue Hill Meteorological Observatory.

The meteorological work of the United States Government was reorganized in 1891, by transferring it from the Department of War to the Department of Agriculture, and by placing it under a civilian director. Professor Harrington was called to Washington to reorganize this important branch of the public service. He assumed his duties, as first Chief of the Weather Bureau, on July 1, 1891, but his resignation as Director of the Observatory was not accepted until some months later. In the meantime the Observatory was left in the charge of Mr. William J. Hussey, then Instructor of Astronomy, who resigned in 1892, in order to accept a position in the new Leland Stanford Junior University.

Professor Asaph Hall, Jr., was selected as Professor Harrington's successor, and filled the office of Director from 1892 to 1905. During this time he was for the most part engaged in work with the Meridian Circle, making observations of Polaris for the determination of the value of the aberration constant. The results of these investigations have been printed in the *Astronomical Journal* and in the *Fourth Report of the Michigan Academy of Science.*

Professor Hall was graduated from Harvard University in 1882, and received the degree of Doctor of Philosophy from Yale University in 1889. From 1889 to 1892 he was Assistant Astronomer in the United States Naval Observatory, the institution to which he returned when he left Ann Arbor.

In 1905, Professor W. J. Hussey, who for nine and a half years had been an Astronomer in the Lick Observatory, was elected Director of the Observatory at Ann Arbor, and entered upon his duties in October of that year. Since then the Observatory has had the continuous support of the President and Board of Regents and many improvements have been made. In the winter of 1905-6, the Observatory Library and the Residence of the Director were reconstructed and enlarged; in 1906, the Observatory Shop was established and repairs to the instruments begun, notably the reconstruction of the six-inch and twelve-inch refractors; in 1907, the construction of the large reflecting telescope was undertaken; in 1908, the Students' Observatory was moved to a new location and a new building added to the original Observatory, having a dome for the large reflecting telescope, clock and class rooms, laboratory, photographic dark rooms, offices, etc.; in 1909, seismographs of modern type were installed in the new building; and in 1911, the large reflecting telescope was completed and spectroscopic work with it begun. Moreover, in 1910, the Observatory Grounds were extended toward the east, by the addition of twenty-six acres of land, the gift of Mr. R. P. Lamont, of Chicago, who graduated as Civil Engineer with the class of 1891. Also, in 1910, the construction of the twenty-four-inch Lamont Refractor was begun, an instrument which is intended for use in the Southern Hemisphere, for work on double stars and for other observations.

In 1911 an arrangement was made with the Universidad Nacional de La Plata by which Professor Hussey became the Director of La Plata Observatory, while still retaining the directorship of the Observatory of the University of Michigan, his time being divided between the two institutions. At this time Professor Ralph H. Curtiss was made Assistant Director of the Observatory at Ann Arbor, in full charge during the absence of Professor Hussey. Dr. Curtiss received the degree of Doctor of Philosophy from the University of California in 1905. He was a Fellow at the Lick Observatory from 1901 to 1905 and Astronomer in the Allegheny Observatory from 1905 to 1907, when he came to the University of Michigan.

The University of Michigan was one of the first in the United States to give advanced instruction in Theoretical and Practical Astronomy, and the officers of the Observatory have always regarded this work as an important part of their duties. As a result of this consistent policy, extending over more than half a century, many important astronomical positions have been filled by those who have studied here, and the work done by these men and by the students whom they have trained in other institutions, has had a wide influence on the development of Astronomy in this country.

The following American Astronomers have been students in the University of Michigan.

James C. Watson, A.B. 1857. Director of the Observatory at Ann Arbor from 1863 to 1879. Discoverer of twenty-two minor planets.

Asaph Hall, Sr., 1856-57. For many years Astronomer in the United States Naval Observatory. Discoverer of the Satellites of Mars.

Cleveland Abbe, Graduate student in Astronomy, 1858-59. Director of the Cincinnati Observatory, 1868-73. Founder of the United States Signal Service. Meteorologist in the Signal Service and Weather Bureau since 1871.

William W. Payne, 1863-64. Director of the Goodsell Observatory of Carleton College, 1871-1908. Director of the Elgin Observatory since 1908. Founder of *The Sidereal Messenger* and of *Popular Astronomy*.

Mark W. Harrington, A.B. 1868. Director of the Observatory at Ann Arbor, 1879-92. Chief of the United States Weather Bureau, 1891-96.

W. F. M. Ritter, A.B. 1871. Sometime Assistant in the United States Naval Observatory and Nautical Almanac Office.

R. S. Woodward, C. E. 1872. Astronomer on U. S. Transit of Venus Commission, 1882--84. Astronomer, U. S. Geological Survey, 1884-90. President of the Carnegie Institution at Washington since 1905.

M. B. Snyder, A. B. 1872. Director of the Philadelphia Observatory.

Otto J. Klotz, C. E. 1872. Astronomer in the Dominion Observatory, Ottawa, Canada.

C. L. Doolittle, C. E. 1874. Director of the Sayre Observatory of Lehigh University, 1875-95. Director of the Flower Observatory of the University of Pennsylvania since 1895.

J. M. Schaeberle, C. E. 1876. Assistant, Instructor, and Acting Professor in the Observatory at Ann Arbor, 1878-88. Astronomer in the Lick Observatory, 1888-98; Acting Director of the Lick Observatory, 1897-98.

George C. Comstock, Ph.B. 1877. Professor of Astronomy in the Ohio State University, 1885-87. Director of the Washburn Observatory of the University of Wisconsin, since 1887.

Mary E. Byrd, A.B. 1878. Director of Smith College Observatory, 1887-1906.

Edward Israel, A.B. 1881. Astronomer on the Greely Polar Expedition.

W. W. Campbell, B.S. (C.E.) 1886. Instructor in Asstronomy in the University of Michigan, 1888-91. Astronomer in the Lick Observatory since 1891; Director of the Lick Observatory since 1901.

A. O. Leuschner, A.B. 1888. Director of the Students' Observatory of the University of California since 1898.

W. J. Hussey, B.S. (C.E.) 1889. Astronomer in the Lick Observatory, 1896-1905. Director of the Observatory at Ann Arbor since 1905. Director of La Plata Observatory, Argentina, since 1911.

A. L. Colton, Ph.B. 1889. Assistant Astronomer in the Lick Observatory, 1892-97.

H. L. Rice, 1889-91. Assistant Nautical Almanac Office, 1892-1902. Astronomer in the Naval Observatory, 1902-07. Professor of Mathematics in the U. S. Navy since 1907.

J. Robertson, B.S. 1891. Assistant in the United States Nautical Almanac Office since 1892.

H. D. Curtis, A.B. 1892. Astronomer in the Lick Observatory.

J. C. Hammond, B.S. (M.E.) 1894. Assistant Astronomer in the United States Naval Observatory.

W. M. Hamilton, A.M. 1896. Assistant Nautical Almanac Office.

S. D. Townley, Ph.D. 1897. Sometime International Latitude Observer at Ukiah. Assistant Professor of Astronomy in Leland Stanford Junior University.

O. M. Leland, B.S. (C.E.) 1900. Professor of Astronomy in Cornell University. Astronomer on demarcation of Alaskan boundary.

Harriet Bigelow, Ph.D. 1904. Director Smith College Observatory.

Frank D. Urie, A.B. 1910. Astronomer in Elgin Observatory.

LOCATION.

The Observatory grounds originally included one city block, about four acres, situated in a northeasterly direction from the University, at a distance of one-half mile from the center of the Campus. By the gift of Mr. Robert P. Lamont, of Chicago, in 1910, these grounds were enlarged by an addition of twenty-six acres, lying east of the original grounds and connecting them with a large City Park and with the University Botanical Gardens.

The Observatory grounds are at the northeastern limit of the city of Ann Arbor. The Huron River is in this direction, at a distance of about one-half of a mile from the Observatory. It runs in a southeasterly direction, at the bottom of a narrow valley, along whose sides rise rolling hills, to an elevation of from one to two hundred feet, formed by glacial action at the time the last ice sheet covered this region. The Forest Hill Cemetery occupies many acres, a short distance southeast of the Observatory, between it and the southerly extension of the city. It has many large forest trees, which shelter the Observatory from the lights in this direction. The Women's Athletic Field, with its well-wooded ten acres, joins the original Observatory grounds on the south.

PLATE II. THE DETROIT OBSERVATORY FROM THE NORTHEAST
1910

PLATE III. THE DETROIT OBSERVATORY FROM THE NORTHWEST

1910

By reason of the nearness of the River, and the character of the topography to the north and east, and the situations of the City Park, the Botanical Gardens, the Forest Hill Cemetery, and the Athletic Field, the Observatory is unusually well protected toward the north, east and south, the directions in which most of its observational work is done. Moreover, it is near the University and readily accessible to students, so near that they are able easily to take advantage of the facilities afforded for training in Practical Astronomy.

The latitude and longitude of the Observatory, referred to the center of the Meridian Circle, are given in the *American Ephemeris and Nautical Almanac*, and in other similar publications, as follows:

Longitude = $5^h 34^m 55^s.19$ West of Greenwich.
Latitude = $+42° 16' 48''.0$.

A telegraphic longitude connection was made in 1861 with the Litchfield Observatory of Hamilton College which had been similarly connected with Harvard Observatory in 1859. The resulting longitude difference, Ann Arbor-Harvard, proved to be + 50m 24.21s ± 0.05s. This difference in combination with the longitude of the Harvard Observatory (4h 44m 30.98s ± 0.04s) as determined through the cable observations of 1866, 1870 and 1872, probably yielded the above value for the longitude of the Detroit Observatory. A second longitude connection with the Harvard Observatory was made in 1869. And on two occasions connections were established with the U. S. Lake Survey Station in Detroit.

The above value of the latitude has apparently come from an approximate value published by Dr. Brünnow, shortly after the establishment of the Observatory. Later investigations have given somewhat larger values. Thus, from observations which he made in 1886-87, with the Three-Inch Transit Instrument, as stated in connection with the description of that instrument, Dr. Ludovic Estes obtained $+42° 16' 48''.66$, as the latitude of the Meridian Circle. From his observations of Polaris, with the Meridian Circle, Professor Hall stated, in 1902, that the latitude could be taken provisionally at $+42° 16' 48''.8$. From direct and reflected observations of twenty-six circumpolar stars, made with the Meridian Circle, in the years 1901, 1902, and 1903, Miss Harriet W. Bigelow obtained $+42° 16' 48''.76$. All of her values were in good agreement; the smallest was $48''.42$, and the largest $49''.35$.

BUILDINGS.

The original Observatory building was completed in the summer of 1854. It then consisted of a central square portion, thirty-three feet on a side, surmounted by the dome for the twelve-inch telescope; and two wings, each nineteen by twenty-nine feet, the one on the east side having a room for the meridian circle, and that on the west side a room for the office of the Director and the Observatory Library. A residence for the Director was added, at the west side of this building, in 1868, and considerably enlarged and improved in 1905-6. It connects with the Observatory, through the Library.

During Professor Watson's administration, the Students' Observatory was erected near the main building, where it remained until 1908, when, to clear the site for the dome of the large reflecting telescope, it was removed to a new situation, about three hundred feet west of the principal building. Professor Watson also obtained another small building, to provide quarters for the meteorological assistants and a "computing room" for the students in Practical Astronomy. In 1906, the Observatory Shop was established in the basement of this building, which is entirely above ground, and, in 1908, when additional shop space became imperative in the course of the construction of the large reflecting telescope, this basement was extended toward the west, for the accommodation of the work then in hand.

In anticipation of the transit of Mercury in 1878, a small building was erected to serve for the photographic operations at that time in accordance with the program adopted by the American observers. This building was placed in the meridian of the three-inch transit instrument, about sixty feet south of it, with a pier just outside the transit room for the heliostat and camera lens, and one just within the photographic house for the reticle plate and photographic plate holder. The heliostat and optical parts which had been provided for this work were not a part of the

equipment of the Observatory. They were loaned by the Federal Government.

This building was used again, in 1882, in a similar manner, at the last transit of Venus. On account of clouds, these observations were only partially successful.

In 1910, this building was removed to the vicinity of the Shop and is now used as an adjunct to the Shop for storage purposes.

What is now the principal building of the Observatory was begun in 1908 and completed in the following year, with the exception of such parts of the dome as could not be finished until the large reflecting telescope was installed. It joins the meridian circle room on the east in the same manner that the residence joins the Library on the west, and has a frontage of forty-four feet on the north, and a length of one-hundred and twelve feet from north to south. It terminates at the south end in a circular wall, forty-three feet high, which supports the forty-foot dome of the large reflecting telescope. The building has two stories, and a basement which is practically above the level of the ground. On the main floor are the offices of the Director and Secretary, a class room, clock room, vault, and entrance and main halls. On the second floor are three offices and two dark rooms. The basement contains rooms for laboratory, office, seismographs, batteries, coal and furnace. The building is well provided with closets for the storage of supplies and for other purposes.

The clock room has brick walls on all sides, and is completely enclosed within the building. It has a window opening into the main hall, closed by two thicknesses of plate glass, with an air space between, set in a single sash. The clock piers have concrete foundations, bedded in hard clay, at a distance of about ten feet below the original surface of the ground. One of the piers is of brick, set in cement; the other is of brick to the level of the clock room floor and from that level a monolith of limestone.

One of the clocks is visible from the hall, and electrical connections are made at the switch-board near the window. The battery room is directly below the switch-board, and a conduit runs from the switch-board to the attic, so arranged that the wiring is readily accessible.

THE TWELVE-INCH TELESCOPE.

The Twelve-Inch Telescope. This telescope was originally constructed by Henry Fitz, of New York, and erected in its present position in December, 1857. It has a clear aperture of twelve and one-fourth inches and a focal length of two hundred inches. At the time of its completion it was one of the large telescopes of the world; the only larger refractors then in existence were the fifteen-inch telescopes of the Pulkowa and Harvard Observatories.

The region about Ann Arbor is covered with glacial drift, consisting of a mixture of clays, sand, and gravel, many feet in thickness. At the Observatory the superficial layers are hard clay, with occasional streaks of fine sand, and the sub-piers of the instruments are set in these clays. The sub-pier for the twelve-inch telescope is a frustum of a circular cone, built of brick, having its base about ten feet below the original surface of the ground, and rising to the level of the dome floor, where it is capped with a large stone which receives the vertical monolith, that forms the pier of this instrument. The center of motion of the telescope is thirty-three feet above the level of the ground immediately outside the building, and in all directions from the building the ground falls away rapidly to lower levels, giving an effective elevation greater than would be obtained from the buildings alone.

The Original Mounting. The original mounting was similar to those of most of the large refractors of its period. Its pier is a limestone monolith, having its upper surface cut to the inclination of the latitude of the place, and carrying at its top an iron base for supporting the bearings of the polar axis. This base also carries the devices for adjustment in altitude and azimuth.

The original tube was made of pine, with a veneer of polished mahogany, and was supported at its center in a cast-iron cradle, fitted to the upper end of the declination axis. Attached to this cradle and to the upper end of the tube were long wooden rods, which, extending to the eye end, were intended for moving the telescope and for carrying the counter-weights. Owing to the flexibilty of these rods they had the disadvantage

of setting the telescope in vibration when it was moved from one position to another.

The movement of the driving clock was controlled by a short oscillating pendulum, whose effective length could be altered to give different rates. The mechanism, however, was too light for the work it had to do, and in consequence the clock proved inefficient and was seldom used.

The worm wheel and the graduated circle in right ascension were attached to the lower part of the polar axis, and the operations of clamping and unclamping in right ascension were effected by throwing the worm in and out of gear. The slow motion in right ascension operated directly upon the worm shaft, by means of a telescoping rod, which could be carried to the eye end of the instrument.

The graduated declination circle was attached to the lower end of the declination axis and the clamp and slow motion in declination were connected with this circle. Owing to these arrangements it was necessary to leave the eye end of the instrument to clamp or unclamp, either in right ascension or in declination, and the slow motions by means of rods not carried upon the instrument itself were inconvenient and inefficient.

The Original Micrometer. The original micrometer is of the Fraunhofer pattern. It has a graduated circle, about four and one-half inches in diameter, divided to quarter degrees, and read by means of verniers to single minutes. The scale is small and the divisions fine, and consequently it is not easy to read under such conditions of illumination as exist when observations are being made.

The micrometer threads are carried on frames moved by screws at either end of the box, but only one of these has a graduated head. Hence, there is no constant position for coincidence of wires, which is not only inconvenient but also a possible source of error in making and reducing the observations.

No observations have been made with this micrometer in recent years. It is regarded as fit for museum purposes only. The value of one revolution of the screw, as derived from the pitch of the screw and the focal length of the telescope is about $11''.15$.

Alterations. In 1907, this telescope was dismounted and many old parts discarded and new ones made to take their places. New parts were substituted as follows:

Tube of sheet steel; draw-tube of bronze, with provision for carrying eye-pieces and micrometer directly, and other pieces of apparatus when these are removed; driving clock of the usual double conical pendulum type; worm and worm wheel; clamps and slow motions in right ascension and declination, so arranged that they may be operated from the eye end of the telescope; coarsely graduated circles; and electric illumination for the micrometer and graduated circles.

With the exception of the micrometer, the new parts were all made in the Observatory Shop, by the Observatory Instrument Makers, Messrs. E. J. Madden, E. P. Pegg, and H. J. Colliau.

Filar Micrometer. In 1907, a new micrometer for this telescope was received from The Warner & Swasey Company, of Cleveland, Ohio. It was beautifully made, but on examination was found to need a number of alterations to give it increased efficiency.

The original graduations had a width of about 0.002 of an inch and were sharply defined when seen under a microscope, such as those employed in reading the graduated circles of a meridian circle. But they were not sufficiently distinct to be read quickly and accurately with the naked eye, under such conditions of illumination as ordinarily obtain in the use of an equatorial telescope. By experiment it was ascertained that graduations having a width of about 0.007 of an inch would be much better, and on returning the circle to the makers they kindly increased the graduations to this width.

Several alterations in the micrometer have been made in the Observatory Shop, by Mr. H. J. Colliau. To secure better illumination of the wires the illuminating apparatus furnished by the makers has been replaced by a simpler and more efficient construction. Teeth have been cut in the circumference of the circle and spur gears fitted for giving the micrometer a quick motion in position angle. Such motion is essential to satisfactory work in the measurement of double stars and for other determinations of position angle.

Several determinations of the value of one revolution of the screw of this micrometer have been

made, some by the method of measuring the difference of the declinations of known stars, and others by the method of transits of circumpolar stars. The results have all been in good agreement. From transits of Polaris, made under excellent conditions, on October 17, 1910, I obtained the following value of one revolution:

$$R = 20''.565 \pm 0''.0001.$$

This determination depends upon transits observed at every half revolution of the screw from the second to the eighty-eighth revolution inclusive.

Dome and Shutter. This is the dome originally constructed to cover this instrument, but modified as stated below. It is hemispherical, with an inside diameter of twenty-one feet, and with a slit thirty inches wide, extending from the level of the center of motion of the telescope, which is eleven feet two inches above the floor, to a point somewhat beyond the zenith.

The dome has a strong wooden frame, supported on a cast-iron base. This frame is covered on the outside, first with wood and then with heavy tin plate, painted white; and on the inside with a thin sheathing of painted wood.

The original shutter for covering the slit moved between grooves, up, over the dome, and down on the side opposite the slit. This was a highly incommodious arrangement and difficult of operation.

The dome was originally supported on cannon balls, which ran in grooves provided for them in the castings, below, on the wall, and above, at the base of the dome. No provision was made for keeping the balls at uniform distances apart and whenever they rolled together the dome could not be moved until the balls were readjusted.

The original observing chair was carried around with the dome and no means were provided for varying its position, forward and back, for the accommodation of the observer.

In 1890, improvements were made converting the dome into one of modern effectiveness and convenience. At that time the present shutter and mechanism for turning the dome were supplied by The Warner & Swasey Company. At the same time a new observing chair of the Burnham-Hough pattern was installed in place of the old one. This chair, in turn, was superseded, in 1907, by a similar one of lighter and more convenient construction.

The present shutter opens horizontally, by a single pull upon the handle attached to the opening cable; and is closed by a single pull upon the handle attached to the closing cable.

The dome is now mounted on a live ring and is easily operated, by hand, by means of an endless rope passing over a sheave. An endless steel cable forms a belt passing around a circular angle iron, attached to the inside of the dome near its base, and over a series of sheaves connected with that carrying the endless rope.

The live-ring consists of eleven rollers, of three wheels each, with their supporting blocks and bearings, guide wheels and connecting rods. These wheels are about seven inches in diameter. The two outside wheels of each roller run upon the planed cast-iron tracks that rest upon the wall; and the middle wheel of each roller receives the weight of the dome, through the planed track upon the lower side of the cast-iron base-plate of the dome.

THE MERIDIAN CIRCLE.

The Meridian Circle was the gift of Mr. Henry N. Walker, of Detroit, at the time of the foundation of the Observatory. It was constructed by Pistor & Martins, of Berlin, and bears the date, 1854. It is mounted in the east wing of the original building, a room whose length in the north and south direction is 26 feet 5 inches, width, 17 feet 8 inches, and height, 13 feet 4 inches. There are windows at the north and south sides of the room, closed by sliding shutters, so arranged that they may be used in connection with the slit to give an opening from the horizon on the north to that on the south. The slit is thirty inches in width.

The foundation walls of the building are of stone and the walls themselves of stuccoed brick. The piers for the instrument and collimators are of brick below the level of the floor, and limestone monoliths above this level. The Meridian Circle is mounted between the faces of two of these monoliths, and the counterweights are supported on the tops of them. The pier below the level of the floor is connected and carries at its center

the support for the artificial horizon, used for nadir observations.

The objective has a clear aperture of 6.3 inches and a focal length of 96.8 inches. About 1902, it was investigated in the Physical Laboratory by Professor Harriet W. Bigelow, now of Smith College Observatory. She examined the structure of the glass by means of Nicol prisms at conjugate foci, and found that the lens, instead of being entirely dark for perpendicular position of the prisms, shows irregular light portions extending toward the center, due to irregular polarization in the glass. She says: "Practically, however, the lens gives excellent star images for meridian work, *i. e.*, small, round disks, of uniform size across the field of view."

The graduated circles are thirty-seven and one-half inches in diameter. The one on the clamp side is divided to 10′ and the other one to 2′. Each of the circles is read by four microscopes, magnifying sixteen diameters, and reading to tenths of seconds of arc. Each microscope is furnished with two pairs of threads separated one and a half revolutions, so that readings upon consecutive divisions of the fine circle may be made by an additional half turn of the micrometer. screw. The microscopes are carried on a ring in such a manner that the distances between them may be altered. The minimum distance apart at which they may be set is about 15°.

About 1893 a Repsold transit micrometer was obtained for this instrument. In addition to the movable right ascension thread and the two usual horizontal threads, it is provided with twenty-five transit threads, arranged in groups of five. There is no movable thread in declination. Settings in this coördinate are made by means of the tangent screw of the instrument.

In the account of his determination of the value of the aberration constant, published in the *Proceedings of the Michigan Academy of Sciences,* for 1904, Professor Asaph Hall, Jr., states that the value of one revolution of the micrometer screw of the Meridian Circle is approximately $3^s.640$. A value in complete agreement with this was obtained by Mr. George A. Lindsay, from observations of transits of Polaris, made on September 7, 1906. He observed 138 transits of the star over the movable thread, during its passage through the field of view, and from these observations he derived the following value of one revolution:

$$R = 54''.610 \pm 0''.007,$$

or

$$R = 3^s.641.$$

The temperature at the time of Mr. Lindsay's observations was 82° Fahrenheit.

The collimators have clear apertures of two inches and focal lengths of about two feet. They are mounted on piers at the north and south ends of the room, in the usual manner, with their lines of sight on the level of the axis of the Meridian Circle.

Dr. Brünnow states that when the Meridian Circle arrived at Ann Arbor, the circle on the side of the clamp was slightly bent, and that it was used merely for setting the instrument, and that the other one only was used for reading zenith distances. He determined the periodic and accidental errors of the latter circle, at intervals of five degrees, and published the details of his investigation in the *Astronomical Notices.* These results are summarized in the accompanying table. The measured errors for every fifth degree are given in the column headed I. These include not merely the accidental division errors, but also the systematic errors arising from the eccentricity of the circle and the departure of the pivots from circular form. The eccentricity produces terms of the form

$$a + b \cos x + c \sin x.$$

By the aid of the values given in column I, Dr. Brünnow found the following expression for the error due to eccentricity:

$$+ 4''.044 - 3''.835 \cos x + 1''.561 \sin x.$$

If the errors due to the eccentricity of the circle be calculated for every fifth degree, by means of this formula, and subtracted from the corresponding errors given in column I, the results given in column II will be obtained. These results have two regular periods; one depending upon the double angle, and the other having itself a period of ten degrees. They are represented by the following expression:

$$- 0''.603 \cos (2x + 74° 20') - 0''.23 \cos 36x.$$

The first term shows that the circle has a small eccentricity, and the latter probably arises from the manner in which the graduations were made.

If these periodic errors are computed by this formula for every fifth degree and subtracted from the corresponding values in column II, the results given in column III will be obtained. So far as this investigation goes, these may be regarded as the accidental errors of graduation. The probable error in the position of any line is $\pm 0''.38$, and the probable error of the mean of four lines is $\pm 0''.19$.

READING	I	II	III
0°	0″.00	−0″.21	+0″.18
5	+1 .51	+1 .15	+0 .98
10	−0 .31	−0 .85	−0 .67
15	+1 .00	+0 .26	−0 .12
20	+0 .67	−0 .30	−0 .32
25	+1 .76	+0 .53	−0 .04
30	+1 .30	−0 .20	−0 .39
35	+3 .00	+1 .20	+0 .48
40	+1 .86	−0 .25	−0 .57
45	+3 .36	+0 .92	+0 .11
50	+3 .20	+0 .42	+0 .05
55	+4 .31	+1 .19	+0 .36
60	+3 .73	+0 .25	−0 .10
65	+5 .11	+1 .27	+0 .49
70	+4 .47	+0 .27	0 .00
75	+5 .91	+1 .35	+0 .69
80	+5 .10	+0 .19	+0 .07
85	+6 .44	+1 .18	+0 .69
90	+5 .46	−0 .14	−0 .07
95	+6 .69	+0 .76	+0 .47
100	+5 .26	−0 .99	−0 .71
105	+6 .78	+0 .24	+0 .16
110	+5 .72	−1 .10	−0 .62
115	+6 .58	−0 .50	−0 .39
120	+6 .45	−0 .86	−0 .21
125	+6 .81	−0 .71	−0 .45
130	+7 .18	−0 .52	+0 .25
135	+7 .15	−0 .71	+0 .36
140	+7 .18	−0 .80	+0 .03
145	+6 .82	−1 .26	−0 .89
150	+7 .46	−0 .69	+0 .12
155	+8 .66	+0 .48	+0 .80
160	+7 .73	−0 .45	+0 .28
165	+8 .07	−0 .08	+0 .12
170	+7 .69	−0 .40	+0 .18
175	+8 .56	+0 .56	+0 .59
180	+7 .50	−0 .38	+0 .01
185	+7 .67	−0 .06	−0 .23
190	+7 .97	+0 .42	+0 .60
195	+6 .77	−0 .57	−0 .95
200	−7″.05	−0″.06	−0″.08
205	+6 .91	+0 .05	−0 .52
210	+6 .81	+0 .23	+0 .04
215	+7 .33	+1 .04	+0 .32
220	+6 .00	−0 .02	−0 .30
225	+7 .65	+2 .00	+1 .19
230	+5 .81	+0 .50	+0 .13
235	+6 .91	+1 .95	+1 .12
240	+4 .46	−0 .15	−0 .50
245	+4 .93	+0 .68	−0 .10
250	+3 .39	−0 .50	−0 .77
255	+4 .23	+0 .70	+0 .04
260	+3 .09	−0 .08	−0 .20
265	+2 .19	−0 .63	−1 .12
270	+2 .20	−0 .28	−0 .21
275	+1 .18	−0 .97	−1 .26
280	+1 .93	+0 .09	+0 .37
285	+1 .62	+0 .08	0 .00
290	+1 .36	+0 .09	+0 .57
295	+1 .67	+0 .66	+0 .77
300	+0 .58	−0 .19	+0 .46
305	+0 .83	+0 .26	+0 .52
310	−0 .04	−0 .42	+0 .35
315	−0 .48	−0 .71	−0 .36
320	−0 .43	−0 .53	+0 .30
325	−0 .42	−0 .42	−0 .05
330	−0 .05	+0 .01	+0 .82
335	−0 .78	−0 .69	−0 .37
340	−0 .49	−0 .40	+0 .33
345	−1 .31	−1 .25	−1 .05
350	+0 .13	+0 .13	+0 .71
355	−1 .66	−1 .76	−1 .73

Miss Bigelow determined the amount of flexure, by combining reflected and direct observations, using the following formulae:

W. D. $\zeta = z_1 + a \cos z + b \sin z - (180° + N) + \alpha,$
W. R. $180° - \zeta = z_2 - a \cos z + b \sin z - (180° + N) + \alpha,$
E. D. $360° - \zeta = z_3 + a \cos z - b \sin z - (180° + N) + \alpha,$
E. R. $180° + \zeta = z_4 - a \cos z - b \sin z - (180° + N) + \alpha,$

where E and W denote respectively clamp east and clamp west; D, direct; R, reflected, and N the nadir reading. She found the coefficient of cosine flexure to be $1''.694$, and that of sine flexure, $0''.117$. "In the case of clamp west the circle readings increase from the zenith toward the north and the formula for the flexure correction is

$$\zeta = z + 0''.162 - 1''.694 \cos z + 0''.117 \sin z - 1''.694."$$

The Chronograph made by Fauth & Company is now located in the entrance hall of the new building, about midway between the clock room and the meridian circle room.

THE LARGE REFLECTING TELESCOPE.

In June, 1906, the Board of Regents set aside the sum of $15,000, as an initial appropriation toward the construction of a large reflecting tel-

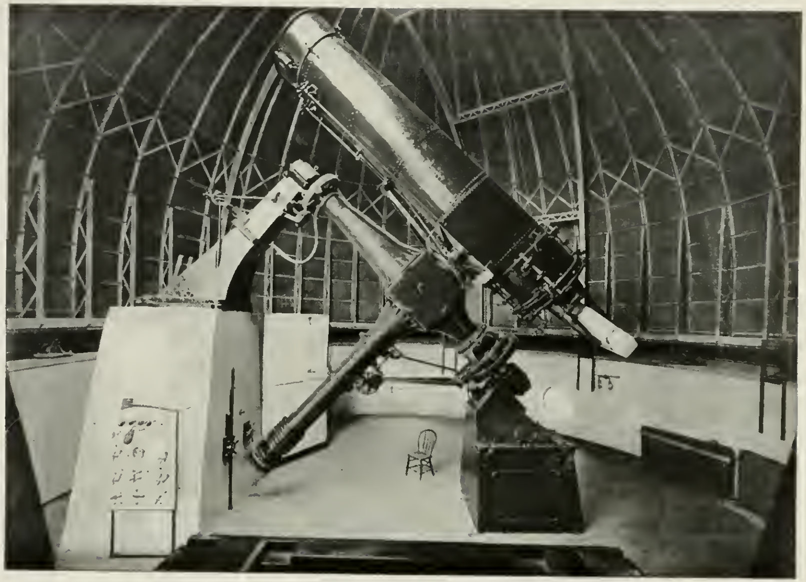

PLATE IV. THIRTY-SEVEN AND ONE-HALF INCH REFLECTOR

escope. In doing so they adopted the plan of having the instrument designed at the Observatory and as largely as possible constructed in the Engineering and Observatory Shops. In each of the three succeeding years, as was planned, additional small appropriations were made for continuing the work, and on the completion of the telescope, in May, 1911, there had been expended upon it and its accessories the aggregate sum of about $24,000. This aggregate includes the cost of designing and constructing the mounting, the special tools required in the shop for the work, optical parts, stellar spectrograph and measuring engine, and the various auxiliary instruments and accessories which are necessary for the successful operation of the instrument.

The Large and Small Mirrors.

The optical parts of the large reflecting telescope were ordered from The John A. Brashear Company, Allegheny, Pennsylvania, in August, 1906, and they were finished and delivered in Ann Arbor in December of the following year.

When the large mirror was ordered it was specified that it should have a clear aperture of at least thirty-six inches, and a focal length of about 19.1 feet; that it should be made of an excellent disk of well-annealed crown glass, not necessarily the grade of crown glass that is used for objectives, but the best quality of crown that is used for large mirrors; that the disk should be about six inches in thickness, and that it should have a central aperture five inches in diameter, so that the telescope could be used in the Cassegrain form of construction. It was further specified that the finished mirror should be parabolic and free from zones, showing no sensible errors under rigorous tests, and that the makers should provide the means of conducting the tests in a satisfactory manner, not only by laboratory methods, but also if required by observations upon stars.

The glass was made at St. Gobain, France, and in its rough state the disk weighed about 650 pounds. It was somewhat larger than specified, and in working it the opticians left it as large as possible. Owing to these circumstances the finished telescope has a larger clear aperture than was first planned. The mirror has an outside diameter of 37⅝ inches. The front edge is slightly beveled, and the diameter of the silvered surface is 37⅜ inches. We commonly speak of the mirror as having a diameter of 37½ inches.

A central hole about three inches in diameter was cast in the disk, and in the course of the work at Allegheny, this was enlarged to the required diameter of five inches. This was in many respects a critical operation, for, in so large a disk, the cutting of a central hole relieves the interior stresses to such an extent that the disk is liable to go to pieces unless it is exceptionally well annealed.

There are three secondary mirrors, each about ten inches in diameter. One of them is plane and the other two are hyperbolic. The hyperbolic mirrors have been finished to such curvatures that when used in connection with the large parabolic mirror, the combination has an equivalent focal length of sixty feet. The position of the Cassegrain focus is about two feet back from the front surface of the large mirror, a position which is very convenient for the spectroscopic work.

Type of Mounting.

The mounting is a modification of the English type. The polar axis is supported at its two ends on separate piers, and the declination axis intersects it a foot below its center. This form of mounting allows the instrument to pass the meridian without reversal and also permits all parts of the sky to be reached with as much facility as with the usual form of equatorial mounting.

The space between the north and south piers is sufficient to permit the free passage of a single prism spectroscope, when attached to the instrument, at all hour angles at which work would be done, up to declination $+60°$.

It is common to work with the tube and spectroscope under the polar axis. The eye-end is then near the floor for all ordinary hour angles, and this is convenient for the observer, since it requires very little movement on his part while making the observations.

The Polar Axis.

The polar axis is sixteen feet long and consists essentially of three castings, two steel shafts, and

two relieving roller bearings, all so rigidly fastened together as practically to form a single piece. The central casting is cubical, and was carefully machined on opposite sides to receive the machined bases of two conical castings, which are firmly attached to it. The relieving roller tires are made of tool steel, and when machined they were pressed upon the upper and lower steel shafts to their designated positions. The smaller ends of the conical castings were bored out and the steel shafts forced into them under heavy hydraulic pressure. After the parts were assembled, the polar axis was finished by grinding all the bearing surfaces to their specified dimensions, in a large lathe, at a single centering. These bearing surfaces include the upper and lower bearings of the polar axis each 6.75 inches in diameter; the relieving roller tires, 9.00 inches in diameter; the bearing for gears on the upper polar axis shaft, 6.80 inches in diameter; and the bearing for the worm wheel on the lower polar axis shaft, 9.25 inches in diameter. The parts of the polar axis have not been separated since these bearings were ground.

The polar axis turns in babbitted boxes, and has relieving rollers near each end, designed to carry the greater portion of the weight. The thrust of the polar axis is taken by a roller thrust bearing, which is supported on an adjustable block.

The two ends of the polar axis are supported on separate piers, each of which is provided with screws for the adjustment of the instrument in altitude and azimuth. When such adjustments are made the alignment of the polar axis bearings would be destroyed if provision were not made for corresponding changes in the directions of the bearings themselves. This is effected by having the bearings in blocks, the outsides of which are finished spherical surfaces. These blocks rest in others, having corresponding concave spherical surfaces, and are held in place in such a manner that they may respond to any changes which may be impressed upon the polar axis in the course of the adjustment of the instrument.

The Declination Axis.

The declination axis is made from a steel forging, and in its finished form it is about eight inches in diameter and nearly seven feet in length. Its diameter at the upper end is enlarged by a flange to eighteen inches, by means of which it is attached to the central casting of the telescope tube.

The declination axis passes centrally through the cube of the polar axis, and its lower end and the counterweights are supported by a conical casting attached to this cube.

The declination axis is provided with roller shaft bearings and with roller thrust bearings at its upper and lower ends. The thrust bearings are so arranged that they take the thrust in both directions with equal facility.

The declination axis has a longitudinal hole, three and a half inches in diameter, bored throughout its length. This is for the passage of the shafts for the operation of the clamp and slow motion in right ascension.

The Tube.

The tube consists of a central section, connected with the declination axis, which carries the ring for the declination clamp and the graduated declination circle; a lower heavy cylindrical casting, to which are attached the cell for the mirror, the carrying frame for the spectroscope, the auxiliary counterweights, the brackets for the clamps and slow motions, and the terminals of the electrical connections; an upper section made of boiler plate riveted together and strengthened by heavy internal bronze rings; and, finally, a short Newtonian section, fitted to the upper end of the tube in such a manner that it may be rotated about the axis of the instrument and clamped in any position.

The central section of the tube is built upon a heavy square casting, to which are fastened two strong cast steel rings, connected by a cylindrical piece of thick boiler plate. By this arrangement this section of the tube is flat on one side, and it is upon this flat side that the cover to the mirror is hinged, as described elsewhere.

Worm Wheel.

The worm wheel is situated near the lower end of the polar axis, with the worm mounted on the north face of the upper south pier casting. The wheel itself is made of cast iron, with an inserted bushing of bronze as the bearing sur-

face, and with an attached ring of bronze upon which the teeth are cut. The diameter of the wheel is very nearly 40.5 inches. It has three hundred and eighty teeth, single thread, three pitch, left hand.

The thrust of the worm wheel is taken by a ball thrust bearing, which encircles the polar axis just below the wheel. The balls are one-half inch in diameter and run between hardened and ground steel plates. The worm wheel was made by the Brown & Sharpe Mfg. Co., of Providence, Rhode Island, and worm by Mr. Emile Colliau, Instrument Maker at the Observatory. The worm is arranged to run continuously in oil.

Driving Clock.

The driving clock is of the usual double conical pendulum type, driven by a weight, which is automatically wound by means of an electric motor. The pendulum system is supported on ball bearings and revolves in five-sixths of a second. The principal axes are carried on roller bearings, running in hardened and ground steel cases.

Quick Motions.

Quick motions in right ascension and in declination have been provided, which are operated by means of hand wheels placed at a convenient height on the south face of the north pier, and also from the top of this pier. The latter provision was made, having in mind the possibility of the use of the instrument in the Newtonian form, in which case an additional observing floor would probably be erected at about the level of the center of motion.

The setting scale for hour angles is placed on the south face of the north pier, near the quick motion handles, and the declination circle can ordinarily be read without difficulty from the same position. This position of the setting handles has, therefore, been found very convenient.

The right ascension quick motion is thrown out of gear by means of a clutch, which is also operated from the south face of the north pier. This clutch throws out of action a long train of gears, including the so-called "jack-in-the-box" system, which is mounted in the upper section of the north pier, and which has for its function to prevent a motion in declination when the telescope is being moved in right ascension.

Slow Motions in Right Ascension and Declination.

Two methods of obtaining slow motion in right ascension have been provided. One is by means of a screw working in an adjustable block which displaces the arm of the right ascension clamp in the usual manner. It is operated by means of hand wheels at the eye end of the instrument.

The other is by differential gears placed between the clock train and the worm wheel. A small electric motor is geared directly to the largest of the wheels of the differential group, and by means of it they may be turned in either direction any desired amount. The motor is controlled by a switch at the eye end of the telescope. This form of slow motion has been found so satisfactory that it is used exclusively. It is especially convenient for guiding purposes with the spectrograph, since it is capable of giving large or small movements as may be desired, without producing appreciable vibration.

The declination slow motion is of the usual form, a screw working in an adjustable block at the end of the arm connected with the declination clamp.

Handles for the clamps and slow motions in right ascension and in declination are provided at both ends of the telescope tube.

Mirror Mounting.

The mirror mounting, taken in all its details, is rather complicated; more than three hundred parts enter into the construction of the cell and the mirror supporting system. The mirror rests upon six felt-covered bronze rings or cups, supported at the ends of three steel levers, which are pivoted at their centers upon blocks that are adjustable in height. Altogether these parts form a well distributed three-point support system for the mirror.

The mirror is held in place laterally by six leather-faced cast-iron blocks, which bear against it near its lower edge and thus prevent any large displacement. These blocks are all adjustable, but those on one side of the cell, when once ad-

justed, remain constant in position, while those upon the opposite side allow of some movement, being held against the mirror with moderate pressure by suitable spiral springs.

A carefully machined bronze ring, about three inches in width, encircles the mirror midway between its upper and lower edges, and is brought into practical contact with it by means of a felt band of such thickness as just to fill the space between. This ring is supported on the shorter arms of twelve levers, mounted to the inner side of the cell, with ball bearings, so that they are free to move about their fulcrums in any direction. The longer arms of these levers carry adjustable lead weights, so proportioned as to balance the weight of the mirror in any position.

Although the telescope is not intended to be brought into a position which will permit the mirror to move away from the bronze cups which support it at the back, provision is made to guard against such contingency by having adjustable holding down pieces, which are normally just in contact with the front surface of the mirror near its edge. These pieces are readily removable and are taken off when the mirror is being silvered.

Silvering the Mirror.

The large parabolic mirror may be resilvered without taking it from the tube and without disturbing its adjustments. Four large man-holes have been placed in the tube, a short distance above the mirror, to give easy access to it. Under ordinary conditions these are closed with wooden covers. When the mirror is to be resilvered the covers are removed, and so also are some of the slow motion rods, which happen to cross the holes, provision being made for readily removing them. The telescope is then placed with the tube in a vertical position, and the holding down clamps removed from the edge of the mirror. To prevent water and the silvering solutions from over-flowing, a band of parafined paper is bound tightly around the mirror, extending about six inches above the polished surface. A parafined wooden plug closes the central aperture. When these arrangements have been made the old silver coating may be dissolved, the surface washed, and a new silver coating deposited, with comparative facility, the successive solutions being removed by taking out the wooden plug and letting them flow through the central aperture into vessels placed below.

Program for Silvering the 37½-inch Mirror.

To ensure success in silvering the large mirror all details must be attended to very carefully. Dr. Curtiss has worked out the following program, which is printed here for convenience of reference.

1. Withdraw electrical plugs and place temperature case in position for removing spectrograph.

2. Let spectrograph down as far as possible by focussing apparatus.

3. By means of the fast motions in right ascension and declination, place spectrograph in position on the temperature case, using wooden shims if necessary and two wooden cross pieces.

4. *Put lead weights on lower end of telescope tube.*

5. Remove nuts and move focussing screws up as far as possible.

6. Push temperature case with spectrograph supported upon it out of the way, at the same time raising telescope to clear the spectrograph ring.

7. Take off the slow motion shafts.

8. Take off the holding down pads on the mirror surface.

9. Place paper dam around the edge of the mirror.

10. Remove old silver with nitric acid.

11. Clean mirror surface carefully with distilled water, leaving one-half of an inch of water (at edges) on the mirror.

12. Add silvering solutions, made up as follows:

Solutions.—To a solution of 200 gms. of $AgNO_3$ in 10,000 ccs. of distilled water add ammonia until the precipitate redissolves. Then add a solution of 100 gms. of KOH in 5,000 ccs. of water. Add ammonia until the second precipitate is nearly dissolved. When ready to silver add 1140 ccs. of the following solution:

Rock candy	90 gms.
Concentrated nitric acid (sp. gr. 1.22)	4 ccs.
Alcohol	175 ccs.
Distilled water	1000 ccs.

This is a stock solution which improves with age.

13. When the surface begins to look milky, drain off the solutions and flush the mirror surface with distilled water. Clean thoroughly.

14. Remove the paper dam while the mirror is still wet and flush the mirror again.

15. Remove water remaining on brass ring.

16. Replace holding down pads on mirror.

17. After the mirror is thoroughly dry, brush and burnish the surface.

18. Replace spectrograph and then remove lead weights.

19. Replace shafts, etc.

Mirror Cover.

The cover to the mirror is placed in the central section of the tube, a little below the declination axis, at a distance of about two feet above the surface of the mirror. This part of the tube is flat on one side, and it was possible to insert there a strong cover, made in one piece, which can be opened and closed at a single operation, like a door. A catch holds the cover in place when it is down. The cover is operated by means of a flexible cord from the eye end of the instrument.

This cover forms a part of the temperature case, described elsewhere. It is constructed of two layers of wood, having a space between, filled with a non-conducting material. The cover closes upon a circular felt ring.

Support for Secondary Mirrors.

The mountings for the hyperbolic and plane secondary mirrors were designed by Dr. Curtiss, with a view to rigidity and minimum light obstruction, together with ease of removal for silvering and ready focal adjustment along the optical axis of the telescope. The removal and replacement of either mirror without disturbance of the collimation adjustment has also been ensured in the design.

A bronze spool, coaxial with the Cassegrain optical system is supported rigidly in place by the usual system of four webs, stretched tightly across the telescope tube. The cylindrical hole, 3⅝ inches in diameter and six inches long, in the spool, is bored to receive a cylindrical casting which divides at the lower end into three spreading struts or legs to the feet of which the back plate of the mirror cell is attached by concentric collimating screws. The back plate of the mirror cell is a bronze annular disk, 11⅜ inches outside diameter, with three bosses on its back face to receive the collimating screws, and with its front surface accurately planed about the edge to receive the cylindrical part of the cell, into which the mirror fits. This cylindrical cell is constructed with a narrow inner flange on its front side, against which rests the edge of the front surface of the mirror, which is held in place by six adjustable steel springs, compressed by screws passing through the back plate of the cell.

The cylindrical tube carrying the mirror cell slides to and from the large mirror through a distance of two and one quarter inches, in the fixed bronze spool, a motion effected by means of a rack and pinion. One end of the pinion shaft carries a wooden handle that may be manipulated at the small mirror; the other end of the pinion shaft extends through the telescope tube to a pair of bevel gears by means of which the focal adjustment of the secondaries may be readily controlled at either end of the telescope tube, by slow motion handles. A given movement of the hyperbolic secondary to or from the large mirror causes a ten-fold change in the position of the focal plane of the Cassegrain combination. Thus the observer may easily alter the position of the focal plane in the Cassegrain form about twenty-three inches. This is much more than is required for seasonal changes and fully enough to make possible the use of extra-focal photometric apparatus, without the removal of the spectroscope. At the same time, with a little experience, this hand motion of the hyperbolic secondary enables an observer to maintain an accurate focal adjustment of the star image for spectrographic work with the minimum of inconvenience.

When a secondary is to be resilvered, the cylindrical tube and cell together are slid out of the fixed spool. The back plate is then unscrewed from the cell, and the cylindrical section of the cell containing the mirror is placed on some flat surface, on which the back surface of the mirror

rests. This part of the cell is then lifted off from the mirror. After silvering, it is obvious that the mirror can be restored exactly to its former position, with no danger of error, since every screw is simply driven home again and the collimating screws are not disturbed nor changed.

Temperature Case.

The early experience with this instrument showed that the rapidly falling temperature during the early evening hours produced optical distortions in the mirror surface, and it was not until a condition of eqilibrium had been reached that the best results could be obtained. Accordingly, to decrease the daily range of temperature of the mirror and spectroscope parts, a temperature case was constructed, within which the lower part of the telescope tube and spectroscope are kept during the day.

The temperature case consists of a wooden frame, carrying a double covering of building paper overlaid with painted canvas, separated four inches, and with the intervening space filled with a non-conducting material. The case is mounted on casters, and may easily be moved from one position to another on the observing floor. It has doors on one side of sufficient size for the entrance of the spectroscope and lower part of the telescope tube. At the end of the night's work the tube is placed in a vertical position, the case is moved up to it, and the doors closed. The lower portion of the telescope tube and spectroscope are then fully enclosed within the case. Here they remain during the day. At night the case is removed when the temperature outside has fallen to that within it, as shown by thermometers, one mounted inside and the other outside of the case, the one within being visible through a small window.

Under average conditions, the efficiency of this case is just sufficient to have the temperature within it equal to that without, an hour or two after sunset, and this may be regarded as the most desirable working condition, since it enables the observer to begin his work soon after dark.

The temperature case is provided with supports for carrying the spectroscope when it is not attached to the telescope.

Focussing for Spectroscopic Work.

The spectroscope is supported by a frame, which may be moved in or out by means of a system of connected screws, operated by two handles similar to the slow motion handles in right ascension and declination. This system is also operated by a ratchet, the handle of which is within easy reach of the observer when looking through the guiding telescope of the spectroscope. By means of the ratchet a very accurate focal adjustment of the spectroscope may be made.

The focal adjustment may also be obtained by altering the distance between the hyperbolic and parabolic mirrors. The hyperbolic mirror is supported in such a way that it may be moved along the axis of the telescope by a rack and pinion, without deranging the collimation. This movement is controlled from the eye-end of the telescope by means of shafts and gears operated by a hand-wheel similar to those employed for the slow motions in right ascension and declination. When care is exercised, this method will give an accurate adjustment of the focus upon the slit, and in practice it is this method that is generally used.

Electric Control at the Eye End.

Every effort has been made to put the instrument under the complete control of a single observer. To this end most of the electrical connections have been carried to the eye end. When an observer is working with the spectroscope, he has circuits under his control, so that he may use them without leaving his position at the guiding telescope, for the following purposes:

1. For turning the dome in either direction, any amount.

2. For giving the telescope a slow motion in right ascension, in either direction, by means of the motor connected with the differential gears in the clock train. This form of slow motion in right ascension has proven so satisfactory that it is used exclusively.

3. For inserting the spark for the comparison spectrum, and for reversing it at pleasure from one side of the slit to the other.

4. For illuminating the hour angle scale and the declination circle.

5. For reading hand lamp.

6. For controlling the small fan motor in the spectroscope box.

The heating and thermostat circuits are also brought to the eye end of the telescope, but they are controlled from the switch-board.

Circuits are also installed on the instrument for illuminating the wires of the double slide plate holder, but these have not yet been used, since all the work of the instrument to the present has been in spectroscopy.

Pier.

The foundation of the pier is a block of reinforced concrete, twenty-eight feet long, twelve feet wide, and nine feet deep, made of broken limestone, gravel, sand, and cement.

A hollow, rectangular, brick pier is built upon this foundation, laid in mortar so rich in cement as to make it practically a cement structure throughout. It is twenty-seven feet long, ten feet seven inches wide, and rises to a height of twenty-eight feet three inches above the foundation. At this elevation the greater portion of the pier is arched over and finished with a level upper surface, on the south end of which stand the large castings, one upon another, which support the south end of the polar axis. The lowest of these castings is approximately rectangular, six feet by five feet at the base, and forms the room for the driving clock. This room has large iron doors on the east and west sides, making the clock easily accessible.

At the north end the brickwork rises seventeen and a half feet higher, in the form of a hollow, tapering, rectangular column, on the top of which are placed the castings which support the north end of the polar axis. The center of motion of the instrument is forty-five feet above the ground.

The brick walls of the pier are thirty-four inches in thickness, and they are connected by two cross walls, one seventeen and the other twenty-five inches in thickness. These walls and the floors divide the space within the pier into a number of compartments, which are accessible by a door in the basement and one on the main floor. The south compartment extends from the top of the pier to the level of the Basement floor, and forms the well for the driving clock weight.

Dome.

The dome for the reflecting telescope is forty feet in diameter and has a slit eight and a half feet in width, which extends from the horizon of the instrument to a point two feet beyond the zenith. The base plate is made of heavy castings, carefully planed and fitted, and rigidly bolted together, to form a complete circle. The principal girders are ten-inch I-beams, bent to the curvature of the dome, and extend from the base plate on one side to the base plate on the other side. They are placed parallel and enclose the slit between them. The secondary girders are six-inch I-beams, bent in a similar manner. They extend from the top of the dome to the base plate, and are at right angles to the principal girders. The remainder of the frame is made up mainly of 4 x 2-inch T-iron, placed three feet apart at the bottom, and converging toward the top of the dome. The dome is covered with heavy copper plate, which is fastened directly to the steel frame. A double shutter closes the slit. It is opened and closed by an endless rope passing over a sheave, connected with the gears and cables which form the shutter operating mechanism. The two halves of the shutter open and close simultaneously, and move parallel to each other.

There are eighteen dome wheels, each sixteen inches in diameter. They are mounted on the top of the wall in frames which are adjustable in height and direction, the adjustment in direction being for the purpose of centering the axes of all the wheels upon a point in the vertical axis of the dome. The base of the dome has a planed under surface, three inches in width, which forms the track. The dome rests directly upon the wheels, and is held in place laterally by nine guide wheels which are mounted on the wall and bear against the planed inner edge of the base plate.

A circular rack, made in sections about three feet in length, is attached to the under side of the base plate near its inner edge, and engages a spur gear which forms a part of the dome operating mechanism. The journals of the

dome wheels run in roller bearings. The dome turns easily and may be readily operated by hand, but an electric motor is ordinarily used for moving it.

The dome was constructed and erected by the Russell Wheel and Foundry Company of Detroit. They did not, however, furnish the wheel work, the guide rolls, the mechanism for turning it and for opening and closing the shutters. These were made by the Observatory Instrument Makers.

Design and Construction.

All the detailed drawings required for shop use in the course of the construction of the large reflecting telescope were made under my supervision at the Observatory. The first design of the instrument, with many of its characteristic features as they exist today, was drawn by Mr. E. J. Madden. This design was carefully studied and the numerous modifications which suggested themselves, were embodied in a later design, drawn by Mr. James H. Marks, who with his assistants worked out most of the details. He also prepared the drawings and specifications of those parts of the instrument which were made on contract. All the details of the spectroscopic and electrical equipment were planned by Dr. R. H. Curtiss, and the success of the instrument in these respects is due to him.

As soon as the design had been so far completed that the general features of the instrument were carefully determined, and the detailed drawing made of those parts which were first to be constructed, the actual work upon the mounting was begun. This was on May 1, 1907. The telescope was completed and ready for modern spectroscopic work four years later. In the year which has passed since its completion, it has been used for spectroscopic work, and more than seven hundred stellar spectrograms have already been secured.

From the beginning it was known that some parts of the instrument would be beyond the capacity of the machine tools of the University and Observatory Shops. These were made on contract. The Brown & Sharpe Manufacturing Company, Providence, Rhode Island, made the worm wheel and clamp ring in right ascension; The Charles F. Elmes Engineering Works, Chicago, Illinois, furnished the bare tube, the polar and declination axes, and two of the large castings for the south pier. The special ball and roller bearings were furnished by the Standard Roller Bearing Company of Philadelphia. All the other parts of the mounting were made by the Observatory Instrument Makers, Messrs. E. J. Madden, H. J. Colliau, E. J. Colliau, Thomas Madden, and Henry Larmee. The Messrs. Madden left the service of the Observatory in 1908, and the others have carried on the work of the last three years. They finished, erected, and adjusted the instrument, and installed its accessories.

COMET SEEKERS.

When the Observatory was founded, a four-inch comet seeker was obtained from Henry Fitz, of New York. It was a portable instrument, mounted on a tripod, and so arranged that it could be used either as an alt-azimuth or as an equatorial. It has been used extensively by students as an instrument of instruction, for the examination of familiar celestial objects.

In 1908, a new comet seeker was constructed in the Observatory Shop, by Mr. Henry J. Colliau. It is an altazimuth instrument, with "broken tube," and cylindrical stand, and is mounted on the roof of the Director's residence, in a situation easily accessible from the twelve-inch telescope. The optical parts of this instrument, an objective of four and one-half inches aperture and a three-inch totally reflecting prism, were furnished by the John A. Brashear Company of Allegheny. The horizontal axis forms a part of the tube, so that, for all zenith distances, the observer looks in a horizontal direction.

On the completion of the new comet seeker, the old one was dismounted, and its tube and objective taken as the finder for the large reflecting telescope.

CLOCKS AND CHRONOMETERS.

Tiede Clock, No. 125. This clock was obtained when the Observatory was founded, and notwithstanding more than fifty years of service, it is still in excellent condition. It was originally rated to sidereal time, and mounted on a pier

near the Meridian Circle, in a convenient position for making observations by the eye and ear method. It was here exposed to considerable variations of temperature, and on this account it was removed to a better situation, on the east face of the brick pier of the Twelve-Inch Telescope, and later still to the clock room in the new building. When it was removed from the meridian room, it was changed to a mean time rate, and has since been keeping Central Standard Time.

Howard Clock, No. 413. This is the usual pattern of Howard astronomical clock. It was obtained about 1893, and first set up in the room adjacent to that containing the Meridian Circle. In 1910 it was transferred to the clock room in the new building. It is rated to keep sidereal time. The pendulum is a steel rod, carrying a cluster of four steel jars, partially filled with mercury, for compensation. The second hand arbor carries a small wheel, whose teeth break the circuit and thus give the clock signals. The tooth corresponding to the 59th second is omitted.

Setting Clock. An inexpensive Seth Thomas clock, having a seconds' pendulum, and rated to sidereal time, is mounted on the wall of the meridian circle room. It is used solely for setting purposes.

Seismograph Clocks. Two inexpensive clocks are provided for giving signals on the seismograph sheets. They are mounted on the walls of the clock room. One is used at a time, and the other held in reserve. By operating through a relay, a single clock gives the signals for the hours and minutes, on the five seismographic records, simultaneously.

Chronometers. The Observatory has two sidereal chronometers, made by T. S. & J. D. Negus, of New York, bearing the numbers, 578 and 721; and one mean time break circuit chronometer, made by William Bond & Son, of Boston, bearing the number 588. The sidereal chronometers have been in the possession of the Observatory for many years. The mean time chronometer was received in 1910.

THE STUDENTS' OBSERVATORY.

In 1880, for purposes of instruction, there were added to the equipment of the Observatory a six-inch equatorial refractor, a three-inch transit instrument, with zenith telescope attachment, both made by Fauth & Company, of Washington, D. C., except that the optical parts were furnished by Alvan Clark & Sons, of Cambridgeport, Massachusetts.

These instruments were installed in what is commonly called the Students' Observatory, a small building of three rooms, an entrance, a transit room, and an equatorial room, situated about a hundred feet southeast of the main building. They remained in this location until 1908, when, to make room for the large reflecting telescope, which now occupies this site, the Students' Observatory was moved to a new location, about three hundred feet west of the principal building.

Six-Inch Equatorial. The six-inch equatorial has a substantial iron pier resting on a concrete foundation, steel tube, means of adjustment in altitude and azimuth, finder, slow motions in right ascension and declination, driving clock, and position filar micrometer with electrically illuminated threads. The value of one revolution of the micrometer screw, as derived by observations of transits of Polaris, is:

$$R = 42''.801.$$

A new driving clock, of the double conical pendulum type, and a new worm and wormwheel, were added to the six-inch telescope at the time of its removal. These improvements were designed by Dr. R. H. Curtiss, and constructed in the Observatory Shop by Mr. Henry J. Colliau. Slow motion in right ascension was provided by inserting differential gears between the clock train and the worm. These are operated by means of a small electric motor, controlled by a switch at the eye end of the instrument.

A camera has been attached to this telescope for photographing comets. It has a Bausch & Lomb-Zeiss Tessar lens, of 4.44 inches aperture and 19.5 inches focal length. When used for photographic purposes, the six-inch telescope becomes a finder, the guiding being done by means of the electrically illuminated threads of the micrometer. For very faint comets, the guiding is sometimes done on stars, in which case the micrometer wires are moved systematically

throughout the exposure to correspond to the rate of movement of the comet, the motion in declination being made by a proper setting of the micrometer in position angle.

Three-Inch Transit Instrument. This instrument is mounted in the meridian and has been used extensively for purposes of instruction. It is well suited to the training of students in the fundamental processes of meridian work, such as the determination of time, latitude, longitude, and instrumental constants.

The instrument has an iron base and standards, and rests on a concrete foundation. It has a clear aperture of three inches and a focal length of 46 inches. It is provided with reversing apparatus, setting circles on the axis reading to 10,″ zenith and striding levels, and a micrometer which may be rotated about the axis, through 90°, between adjustable stops. By reason of this rotation, the movable micrometer thread may be used either as a transit thread, or for the measurement of zenith distances. The sensitive zenith level is mounted on the setting circle, and has a clamp and tangent screw attached so that it may be set in any position. By reason of these arrangements, the instrument is suited to the determination of latitude by Talcott's method. From observations of 138 pairs of stars, by this method, made between October 6, 1886 and February 9, 1887, Dr. Ludovic Estes, determined the latitude of the Observatory, with the result

$$\phi = + 42° \ 16' \ 48''.66 \pm 0''.051,$$

referred to the latitude of the meridian circle.

The value of one revolution of the micrometer screw of this instrument is

$$R = 45''.031 = 3^s.002.$$

The value of one division of the striding level is $2.''750 = 0^s.183$, and that of the zenith level $0.''807$.

SEISMOLOGICAL EQUIPMENT.

Seismoscopes. During Professor Harrington's administration of the Observatory two small seismoscopes were obtained. One of them was mounted on the sub pier of the Meridian Circle and the other on the pier in the house intended for the transit of Mercury observations. These instruments were intended only to indicate the existence of seismic disturbances, without giving any other records of them than the times of their occurrence. Each of these instruments consists essentially of a vertical pendulum, hinged freely near its lower end, where it carries a small steady mass; and a light lever whose longer arm terminates in a point and is so bent that it can be adjusted to rest lightly upon the upper pointed end of the pendulum. By the action of the shock this adjustment was disturbed, and the lever, by altering its position, through mercury contacts, closed an electric circuit, which was arranged to stop a clock.

New Equipment. In August, 1909, a set of modern seismographs was installed in one of the basement rooms of the new building. The instruments include two Strassburg tromometers, of the Bosch-Omori pattern, a Wiechert astatic horizontal seismograph, of two components, and a Wiechert vertical seismograph.

These instruments rest upon a concrete pier, bedded in hard clay. It is impracticable here, on account of the region being covered with a thick layer of glacial drift, to carry the pier down to a rock foundation. The pier is isolated from the floor of the room and the walls of the building, by having a free space entirely around it, a few inches in width, extending down to a depth of about three feet.

All of these instruments have mechanical registration on smoked paper. A single clock, located in the clock room, working through a relay, furnishes the time record of hours and minutes on all the sheets simultaneously.

The Strassburg Tromometers. A modern seismograph consists essentially of a supporting pier, a pendulum which may be either vertical or horizontal and whose weight is called the "steady mass," and some means of recording the movement of the pendulum relative to the earth and the times of occurrence of such movements.

The so-called Strassburg tromometer is a seismograph, having a horizontal pendulum, made by Messrs. J. & A. Bosch, of Strassburg, Germany, according to the designs of the eminent Japanese seismologist, Dr. Omori. It has a steady mass of two hundred and twenty pounds, suspended in such a manner that it is free to

PLATE V. SEISMOGRAPH ROOM

move in a horizontal plane. A light trussed rod is fastened to the steady mass on the side opposite the supporting pier, and the outer end of this rod is pivoted lightly to the shorter arm of a magnifying lever whose longer arm carries the writing point. A cylinder carrying a sheet of smoked paper is kept in continuous movement by clock work, controlled by a governor of the double conical pendulum type. The friction of the writing point and of the pivot of the magnifying lever is not large, and when in adjustment the instrument is extremely sensitive and gives good records even of very distant disturbances. The instrument is provided with air damping mechanism.

In the installation of these instruments, the plane of suspension of one of them was made to coincide with the plane of the meridian, and that of the other with the prime vertical. They register, therefore, the east-west and north-south components, respectively, of earthquake disturbance.

Wiechert Horizontal Seismograph. This instrument has an inverted vertical pendulum, an air damping device, and recording mechanism. The pendulum has a steady mass of two hundred and twenty pounds, which is carried at its upper end, about forty inches above its support. It is supported at its lower end by two pairs of flexible steel bands, set at right angles to each other, in such a way that the pendulum, when disturbed, is free to move a limited amount about any horizontal axis passing through this support. Two thrust arms are connected with the steady mass, at right angles to each other, one in the north-south and the other in the east-west direction. These arms are connected with aluminum levers, which in turn are pivoted to the air damping devices and to the magnifying and writing mechanism. The levers are so arranged that both components of disturbance are recorded side by side on the same sheet. The air damping device consists of a light piston working closely in a brass cylinder, and is regulated by partially opening or closing a tube which connects the two ends of the cylinder. The damping may be cut off entirely or varied to any extent up to complete aperiodicity.

The magnification of the instrument may be varied from 40 to 160 times, and the period of oscillation from four to twelve seconds. By the use of steel bands for the supports much friction has been avoided, and that of the writing points and pivots has been reduced to a very small amount. The record of the clock signals for minutes and for hours is made by the writing point itself; when contact is made it is drawn aside for the moment by the action of an electromagnet.

Wiechert Vertical Seismograph. This instrument has a stationary mass of about one hundred and seventy-five pounds, placed at one end of a horizontal beam, which is pivoted at the other end and is supported near its center by a strong spiral steel spring. This spring is suspended from one end of a lever whose fulcrum rests upon the top of a gridiron column, made of zinc and steel rods, in the same manner that pendulums for clocks are sometimes constructed. The strength of the spring varies with changes of temperature and compensation is necessary to prevent displacements of the writing point, corresponding to variations of temperature. The gridiron column is intended to furnish the required compensation. In order that the injurious effects of rapid changes of temperature may be diminished as far as possible, the spring is enclosed in a wooden box and the entire upper part of the instrument is further enclosed in a double wooden case, having an air space between its layers.

An arm attached to the horizontal lever which carries the steady mass is pivoted to a double aluminum lever which connects with the air damping device and with the recording mechanism. The damping device is similar to that of the Wiechert horizontal seismograph. The period of the instrument is about six seconds and the magnification may be varied from forty to one hundred and sixty times. The record is made on a horizontal cylinder carrying a sheet of smoked paper, and the writing point is also used to mark the minutes and hours.

The Weichert seismographs were made by Messrs. Spindler & Hoyer, of Göttingen, Germany.

The Rossi-Forel Scale of Earthquake Intensities. This scale is extensively used for indicat-

ing the intensities of earthquake shocks, and for convenience of reference, we quote it here in the form given in the *Bulletin of the Seismological Society of America*.

I. MICROSEISMIC SHOCK: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. EXTREMELY FEEBLE SHOCKS: recorded by several seismographs of different kinds; felt by a number of persons at rest.

III. VERY FEEBLE SHOCK: felt by persons at rest; strong enough for the direction and duration to be appreciable.

IV. FEEBLE SHOCK: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. SHOCK OF MODERATE INTENSITY: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. FAIRLY STRONG SHOCK: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. STRONG SHOCK: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. VERY STRONG SHOCK: fall of chimneys, cracks in walls of buildings.

IX. EXTREMELY STRONG SHOCKS: partial or total destruction of buildings.

X. SHOCK OF EXTREME INTENSITY: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

THE OBSERVATORY SHOP.

A modern Observatory makes many demands upon the Instrument Maker. New instruments must be installed; old instruments must be cared for and kept in a reasonable state of efficiency; auxiliary apparatus must be fitted to existing instruments and adapted to new needs; new forms of apparatus must be created for special investigations, and, from time to time, modified to meet the requirements of research. So numerous and varied are these demands that an Instrument Shop has become a necessary adjunct to a modern observatory. This is particularly true when astrophysical work is being done, where many experiments must be tried, and where special forms of apparatus are to be prepared under the immediate supervision of the experimenter.

On taking charge of this Observatory in October, 1905, I saw at once that extensive alterations would be required to put the instruments which it then possessed in a satisfactory condition for modern work; and that new and more powerful instruments, with much auxiliary apparatus, would have to be added, to enable the Observatory to undertake any investigations in the important department of astrophysics. Accordingly, upon my recommendation, by the action of the Board of Regents, in November, 1905, an Observatory Shop was established, for the repair and construction of instruments.

In the beginning, it was expected that the principal work of this shop would consist in making the lighter repairs to the instruments which the Observatory then had, and in constructing the auxiliary apparatus which would be needed in connection with them. It was accordingly fitted with excellent tools of moderate size, which have been in nearly constant use since their installation. But, after a time, it was found desirable to proceed to larger constructions than were originally contemplated, and to meet the increased demands, the shop space was enlarged and some additional machines obtained. At present the shop has two rooms, one 18 x 18 feet, and the other 18 x 46 feet, with the following equipment of power machine tools:

1 Pratt & Whitney Toolmakers' Lathe, 10-inch swing, 29 inches between centers, with full complement of chucks and tools.

1 Hendey Machine Company Lathe, 24-inch swing, 16 foot bed, 11 feet between centers, with full complement of chucks and tools.

1 Brown & Sharpe Universal Milling Machine, No. 1½, with slotting and vertical milling attachments, with arbors, cutters and tools.

1 Potter & Johnston Universal Shaper, 24-inch.

1 Cincinnati Milling Machine Company's Universal Tool Grinder, No. 1, with all attachments.

1 Barnes Drill Press, 20-inch.
1 Bench Drill Press.
1 General Shop Grinder.

In addition to the machine tools enumerated above, the Shop is supplied with a forge and a full complement of hand tools, such as are needed for accurate instrument work, and also with appliances for handling the large forgings and castings which are now being machined as parts of the twenty-four-inch Lamont refractor.

The Hendey lathe and the Potter & Johnston shaper were presented to the Observatory, in 1910, by Mr. R. P. Lamont of Chicago.

The Observatory has profited in its larger constructive operations by the courtesy of the Dean of the Engineering Department and the Superintendent of the Engineering Shops, who have placed their large tools at the disposal of the Observatory Instrument Makers, thereby enabling them to handle larger work than otherwise would have been possible.

The Observatory Shop has been taxed to its utmost capacity from the time of its foundation. Heavy duties have been laid upon it by the many repairs and smaller pieces of work which have been undertaken; by the very general reconstruction of the six-inch and twelve-inch refractors; by the design, construction, and erection of the thirty-seven and one-half inch reflector; by the completion of the stellar spectroscope, with its carrying frame and temperature case; by the installation of apparatus in the new building; and by the work now in progress; viz., the construction of two special engines for the measurement of celestial photographs, and the design and construction of the twenty-four-inch Lamont refracting telescope.

In the six years since its establishment, six Instrument Makers have been employed in the Observatory Shop, usually three or four at a time.

Mr. E. J. Madden was first appointed. He began work in January, 1906, and remained until June, 1908. In this interval, in addition to many miscellaneous duties, he organized the Observatory Shop, constructed the tube and driving clock for the twelve-inch telescope, made the preliminary drawings for the large reflecting telescope, and constructed the driving clock and portions of the north and south piers for this instrument. In the work upon this telescope, he was assisted by his brother, Mr. Thomas Madden, from May, 1907, to April, 1908.

Mr. Henry J. Colliau came to the Observatory in January, 1907 and his brother, Mr. Emile Colliau, in August of the same year. They have since been constantly employed here and have taken a conspicuous part in the production and installation of the equipment of the Observatory. It is not possible to notice in detail the many pieces of work which they have carried to successful completion. It should be mentioned, however, that they have constructed many of the parts of the large reflecting telescope, and, aided by Mr. Henry Larmee, who has been working with them since March, 1909, they have completed this large instrument, erected it in its dome, and put it in complete working order, without the necessity of calling in outside assistance.

During the past two years a large part of their time has been devoted to the miscellaneous accessories of this instrument and to the construction of the twenty-four-inch Lamont refractor.

Mr. E. P. Pegg was employed as an instrument maker at the Observatory for six months, in 1907, and with Mr. Henry J. Colliau, did much of the reconstruction of the twelve-inch refractor.

All the detailed drawings required for shop use have been made at the Observatory, under my supervision. The original design for the large reflecting telescope, exhibiting many of the features of the instrument as it exists today, was redrawn by Mr. James H. Marks, who with his assistants completed it in nearly all its details and embodied numerous modifications which, after careful study, it seemed desirable to make. He also prepared the drawings and specifications for the contract work on the instrument, and did much of the supervision of the work in the shop. All the details of the spectroscopic and electrical equipments have been planned by Dr. Curtiss and the success of the instrument in these respects is due to him.

The twenty-four inch Lamont refractor has been designed and developed in all its details by Mr. S. P. Langley, who has also had the supervision of its construction in the Shop.

LIBRARY.

The West Wing of the main building contains the Observatory Library. It has about twenty-seven hundred bound volumes and several hundred unbound books and pamphlets. It is composed almost entirely of technical works on Astronomy. It has nearly complete sets of the more important astronomical periodicals, the publications of the leading observatories and astronomical societies, and the principal treatises on theoretical and practical astronomy and astrophysics. The collection of star catalogues is large.

This is a department library, and does not attempt to duplicate the works found in libraries of other departments, or those contained in the General Library of the University. It does not, therefore, contain many books on pure mathematics, physics, chemistry, meteorology, etc., nor the proceedings of learned societies of a general character. Such works are naturally to be found in the General Library or in other department libraries, and when they are contained in such collections they are readily available for reference.

METEOROLOGICAL OBSERVATIONS.

Regular meteorological observations were begun at the Observatory in 1881 and have been continued without interruption since that date. From 1881 to 1904 inclusive the observations were made at 7:00 a. m., 2:00 p. m., and 9:00 p. m., as was done at all stations which were furnishing data during that period for the Michigan State Board of Health. This Board discontinued the collection of meteorological information in 1905, and since then the observations here have been made at 7:00 a. m. and 7:00 p. m., the hours adopted for making the observations by the United States Weather Bureau.

At present the observations made include the following: Atmospheric pressure, as determined by the standard mercurial barometer; air temperature, from properly exposed mercurial thermometers; direction and velocity of wind, from wind vane and anemometer; precipitation and cloudiness. Continuous instrumental records are also obtained of the velocity of the wind, as recorded by the anemometer; of the air temperature by a Richard thermograph; of the relative humidity by a Richard hygrograph and of the atmospheric pressure by a Richard aneroid barograph.

Public Service. From 1881 to 1904 inclusive, the meteorological results obtained at this observatory were communicated at the end of each month to the Michigan State Board of Health, for use in their investigations. In 1905 this Board ceased to collect information relative to the meteorological conditions within the state, the work being fully covered by the United States Weather Bureau.

The observations of this observatory have been regularly furnished the United States Weather Bureau, at the end of each month, and are now sent to the central station at Grand Rapids.

From April 1 to Septemer 30 of each year, the morning observations are telegraphed at 7:00 a. m., to the United States Weather Bureau Station at Chicago, for the use of the Corn and Wheat Section of that Bureau. Observations are also sent each morning by post card to the Ann Arbor Times-News, for publication in its columns.

May, 1900.

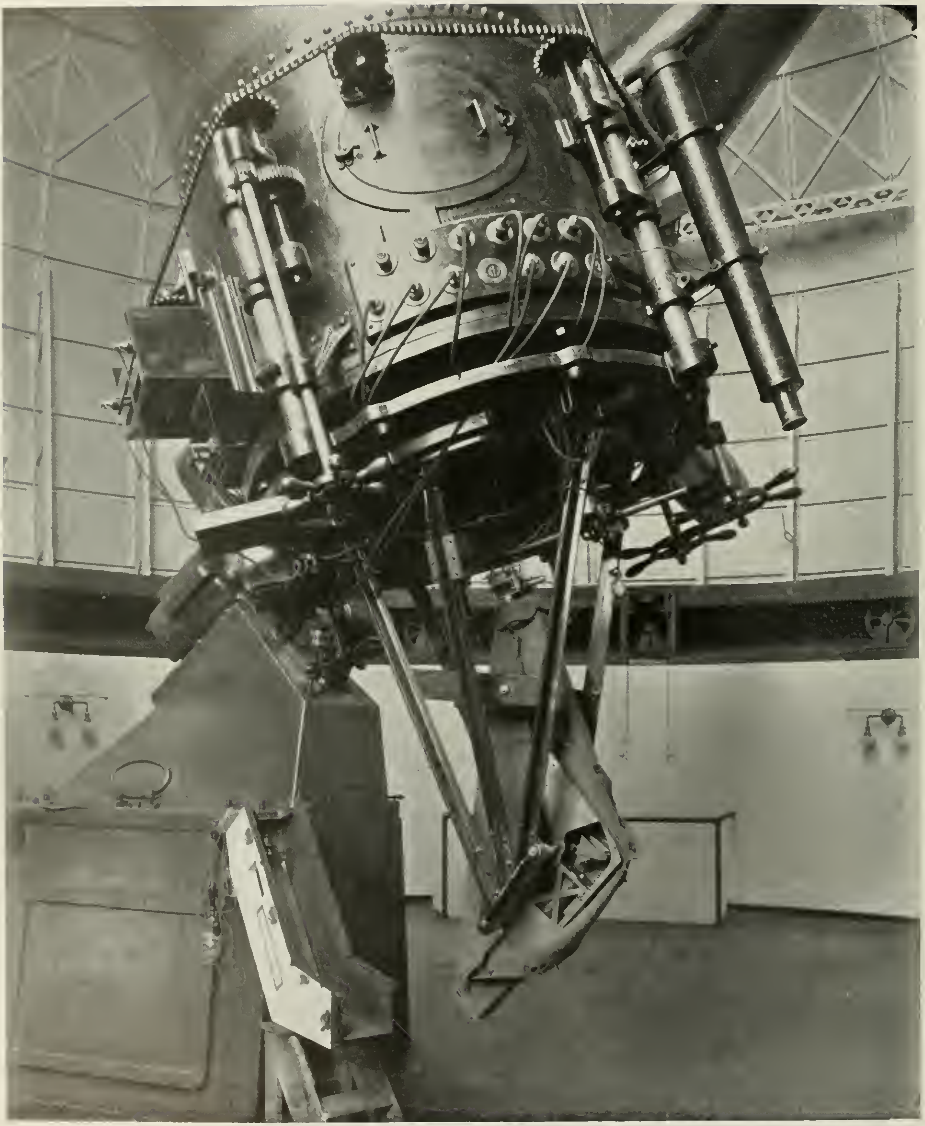

PLATE VI. SINGLE-PRISM SPECTROGRAPH

THE SINGLE-PRISM SPECTROGRAPH OF THE DETROIT OBSERVATORY.

By RALPH H. CURTISS.

The successful application of the single-prism spectrograph of the Lick Observatory to the study of the spectra of relatively faint Cepheid variables led the writer, in 1905, to recommend a program of low dispersion radial velocity work in connection with the Keeler Memorial Reflector of the Allegheny Observatory. The spectra of so-called early type, containing broad diffuse lines, seemed particularly adapted to study with a spectrograph of low dispersion. This class of stars alone, comprising as it does the short period Algol stars available for such studies as well as numerous other exceptional objects of great interest, promised a rich field for investigation. A year and a half later, though this domain of astrophysics had been entered by several new investigators, the problems involved seemed even more pressing and no hesitation was felt in deciding upon a program of low dispersion quantitative and qualitative spectrographic work in connection with the then projected reflecting telescope of the Observatory of the University of Michigan.

In March, 1907, Professor Hussey placed the order for the new spectrograph with the John A. Brashear Company of Pittsburgh, Pennsylvania. This order specified an instrument of the same general type as that of the Mellon Spectrograph of the Allegheny Observatory, with such changes as the writer might specify. These changes were embodied in an entirely new set of drawings of which those for the brass box or spectrograph proper were submitted to the John A. Brashear Company and were adapted to shop use. That the work of this firm was excellently done need not be said. The spectrograph box complete with optical parts, slit-head, comparison apparatus, plate holders, thermostat and thermometers, was delivered in Ann Arbor, in January, 1909.

Investigations of the optical parts and mechanical construction were immediately undertaken and the results were embodied in papers read before the Astronomical and Astrophysical Society of America in the following August. These results also appear in this volume. With the successful termination of these investigations it became possible to complete the design for the supporting truss, constant temperature case, and guiding microscope, and by special arrangement with the John A. Brashear Company these were constructed from our designs in the Instrument Shop of this Observatory.

With the completion of the large reflecting telescope the spectrograph went into use, the first spectrogram being made early in 1911. A regular program was begun in the following May, yielding exposures on stellar spectra numbering six hundred and fifty to the first of June, 1912, sufficient to give assurance of the success of the instrument.

DESIGN.

The stellar spectrographs of the present time may be considered in two general classes according to the type of mechanical construction employed. In the first type the supporting system and the spectrograph proper form a single unit in the form of a cantilever beam. This type of spectrograph seems relatively more liable to flexure displacement of spectral lines at the camera focus and is not as adaptable as possible to temperature control. In the second type of stellar spectrograph the optical parts, slit head and plate holder are combined in one distinct unit, forming the spectrograph proper; this to be carried, with every essential provision for relative motion, by an independent truss or supporting cradle, in position at the focus of the telescope. In this type of instrument flexure effects are readily controlled and the construction and support of the temperature case is facilitated. This second type of spectrograph originated at the Lick Observatory and, as developed by Wright, is represented well in the Southern Mills' Spectrograph, used in Chile by its designer

and described in Volume IX of the *Publications of the Lick Observatory*. A second instrument built upon this principle, but embodying new ideas of Campbell and Wright, was completed at the Lick Observatory in 1902, and immediately supplanted the original Mills spectrograph, as the chief observing instrument for the extensive radial velocity programs of the Lick Observatory. It was this instrument which served as a prototype for the single-prism spectrographs which have recently been constructed at Allegheny, Ottawa, and Ann Arbor.

The Mellon Spectrograph of the Allegheny Observatory was the first permanent single-prism instrument of this type. In it were embodied the writer's ideas, as gained during several years' work at the Lick Observatory and as developed under the supervision of Professor F. Schlesinger. But aside from the modifications necessary to adapt the construction of the New Mills Spectrograph to the requirements of the single-prism type, no important new features were introduced in the design.

The success of the Mellon Spectrograph in its particular field needs no further demonstration. To the writer no far reaching measure toward improvement in its mechanical construction seems obvious. But upon considering possible modifications for a larger and heavier instrument for this Observatory, several changes, partly experimental, seemed worthy of adoption largely on the basis of experience with the Allegheny instrument.

SINGLE-PRISM SPECTROGRAPH OF THIS OBSERVATORY.

In the design of the moving spectrograph intended for quantitative work on stellar spectra at the University of Michigan, the chief desiderata in view aside from "identity of source," were excellence of definition over a large region of the spectrum, light efficiency, invariability of position of photographic images on the plate during exposures, and convenience of manipulation. It was intended to sacrifice dispersion and resolving power only so far as necessary to the furtherance of the above ends, keeping in view the requirements prescribed by the nature of the investigations intended.

THE OPTICAL PARTS.

In selecting optical parts with the above considerations in view there was no hesitancy in adopting the Hastings-Brashear Single Material Camera Doublet, as tested successfully at Ottawa.

The prism of O:102 glass was selected at once, but the Isokumat Collimator Lens was taken on trial, because of the well-known strong light absorption of one of the elements of this lens.

THE COLLIMATOR LENS.

The dimensions and focal lengths of the optical parts represent a compromise between considerations of dispersion and resolving power on the one hand, and of light efficiency and compactness on the other. The Isokumat Collimator Lens has an aperture of 36.6 mm. (1.43 inches) and a focal length for $H\beta$ light of 686 mm. (27 inches).

THE PRISM.

The prism is constructed of O:102 glass, bearing the number 0.3732. The makers' indices of refraction are as follows: 1.6413 for $H\alpha$ ($\lambda = 6563.1$ Å), 1.6467 for D ($\lambda = 5893.2$ Å), and 1.6603 for $H\beta$ ($\lambda = 4861.5$ Å). On the basis of these indices the constants of a Hartmann interpolation formula are found to be $n_0 = 1.6113$, $\lambda_0 = 2185$, and $c = 131.17$. And the value of the index of refraction for $\lambda = 4415$ Å is found to be 1.6701 and for $H\gamma$ ($\lambda = 4340.6$ Å), 1.6722. A deviation of 60° for $H\gamma$ light having been determined upon, the refracting angle of the prism was made 63° 36′, and to make full provision for the free path of the beam the height of the prism was made 43.2 mm. (1.70 inches) and the length of the refracting faces, 74.4 mm. (2.93 inches). The proportion of $H\gamma$ light transmitted by this prism, not considering losses by reflection, was found on theoretical grounds to be about eighty-one per cent. and maximum transmission was secured when the refracting edge was placed three fourths of a millimeter inside of the edge of the beam. In actual practice the refracting edge of the prism is placed about one and a quarter millimeters inside of the edge of the beam.

THE CAMERA LENS.

The camera objective is a Hastings-Brashear single material doublet figured on the basis of the Hartmann-Zeiss homogeneous doublet of 1900. The objective of sixteen and one-half inches (420 mm.) equivalent focal length, consists of two lenses of light crown glass, five inches apart, with apertures of 1.75 inches (44.4 mm.) and 2.75 inches (69.8 mm.), carried in a bronze cylinder of about three inches outside diameter. The distance from the front lens to the focus is about seventeen and one-half inches (444 mm.). The inclination of the focal plane to the axis of the lens is about eighteen degrees.

When used in connection with a single prism and an Isokumat collimator lens, Plaskett has found this lens to be remarkably free from spherical aberration over a wide range of its unusually flat focal surface. A more intensive study has been attempted here, in order that every possibility of this particular lens might be realized, and the methods and results, the latter on a readily interpretable scale, will be useful to those contemplating optical parts of this kind.

In testing this combination the collimator focus for $H\beta$ light was first determined by Schuster's method. $H\beta$ was placed at minimum deviation and the inclination of the plate holder was adjusted to follow closely the focal curve. For any given adjustment of the optical parts the actual focal curve with reference to the plane surface of the photographic plate was determined by making eight exposures of sky spectra side by side on the same focus plate. Between each of these exposures the camera lens was moved along its axis a distance of 0.2 mm by means of a screw threaded in a nut fixed rigidly to the lens cell. Each plate was examined under a microscope, and for a large number of groups of Fraunhofer lines, throughout the spectrum, estimates were made of the camera settings which would give the best definition. These estimates of camera settings, plotted against distances measured along the spectrum, furnish for any given focus plate the focal curve or curve of best focus with reference to the plate surface. This method avoids some objectionable features of extra focal observations and is capable of high accuracy.

The plates used in this investigation were Seed 23's, Seed Red Label Lantern Slides bathed in Pinachrome, and Cramer Spectrum Process Plates. The range of spectrum covered was from λ 3850 Å to λ 6000 Å.

In the manner described focal curves were determined for nine different cases, as shown in Plate VII, involving nine different combinations of collimator and prism settings. Three settings of the collimator, one-eighth of an inch outside and the same distance inside of the $H\beta$ setting and the $H\beta$ setting itself, were combined separately with three prism settings at minimum deviation for λ 3900, $H\beta$ and λ 6500. In the figure the first, second and third rows of curves correspond to minimum deviations for the rays, λ 3900, $H\beta$ and λ 6500 respectively. The first, second, and third columns correspond to collimator settings one-eighth of an inch inside of the $H\beta$ setting, the $H\beta$ setting, and one-eighth of an inch outside of the $H\beta$ setting respectively. Thus, these nine cases cover all possible combinations that might be advantageous in practice. From them it is possible to determine the best adjustment of the optical parts for the greatest flatness of field.

As indicated in the illustration, the horizontal spaces correspond to 0.2 mm. measured parallel to the optical axis of the camera lens. Wave lengths are indicated in the upper middle curve.

It is obvious at once that the general inclination of the focal curves is strongly affected by change of the optical adjustment; but since the plate holder is adjustable to any inclination, this does not concern us at present. We are interested, however, in the deviation of the curve from a straight line, for this is the measure of the departure of the curve from flatness. This deviation of the curve from a straight line may be investigated over either a given range of spectrum or a given linear distance along the spectrum. And in the figure the full lines through each curve show the deviation of the focal curves from a straight line from λ 4000 to λ 5900. The dotted lines exhibit the same deviation over a range of thirty-four millimeters measured from λ 5900 toward the violet end of the spectrum.

It is evident at once that the deviations for the fixed distance of thirty-four millimeters vary but

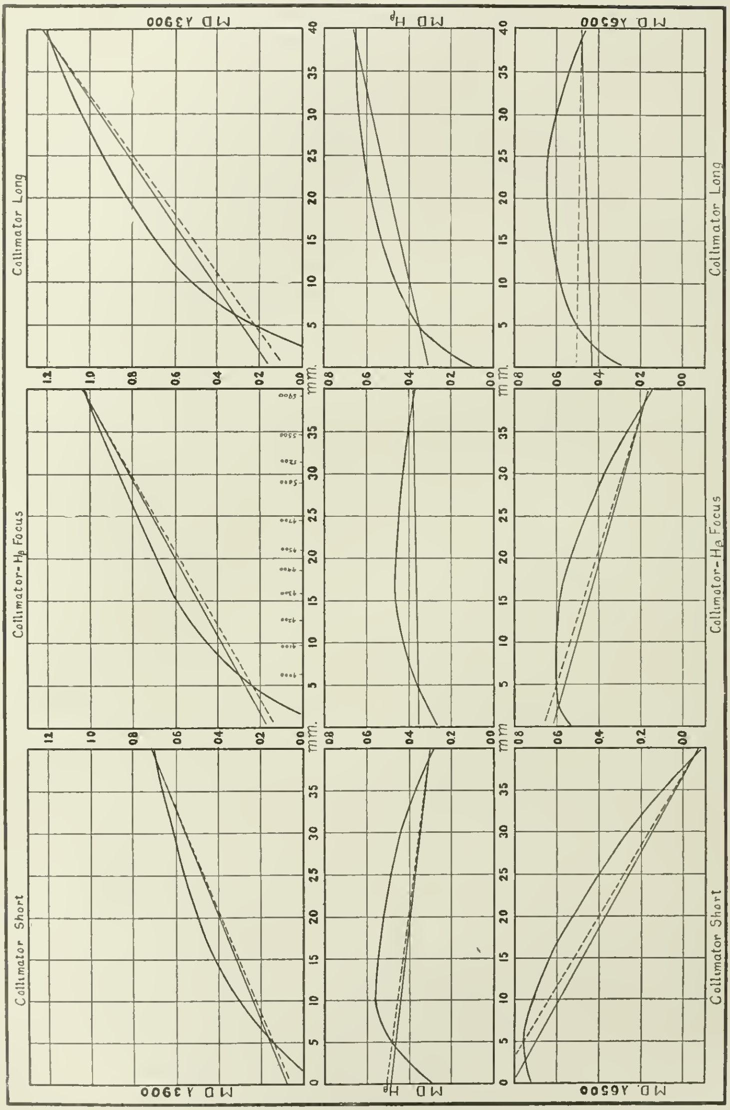

PLATE VII. FOCAL CURVES OF THE SINGLE-PRISM SPECTROGRAPH.

little for all nine cases. It is to be noticed, however, that the form of the curve on the end of shorter wave-lengths differs considerably in different combinations, seeming to diverge faster for longer collimators with minimum deviation settings for longer waves. But curve 2 is an exception, in which the curvature of the plate surface is probably involved. Again, the point of maximum deviation from the plate surface seems to shift slightly toward the red for minimum surface between λ 4000 and λ6000 is dependent upon the optical adjustments. For the longest collimator the flattest curve is secured with a minimum deviation at about λ 4700. For the Hβ collimator setting the flattest curve is obtained with λ 4400 at minimum deviation, and for the short collimator the best curve is obtained with λ 4100 at minimum deviation. But for each length of collimator the best curves seem to be about equally good, except possibly for the de-

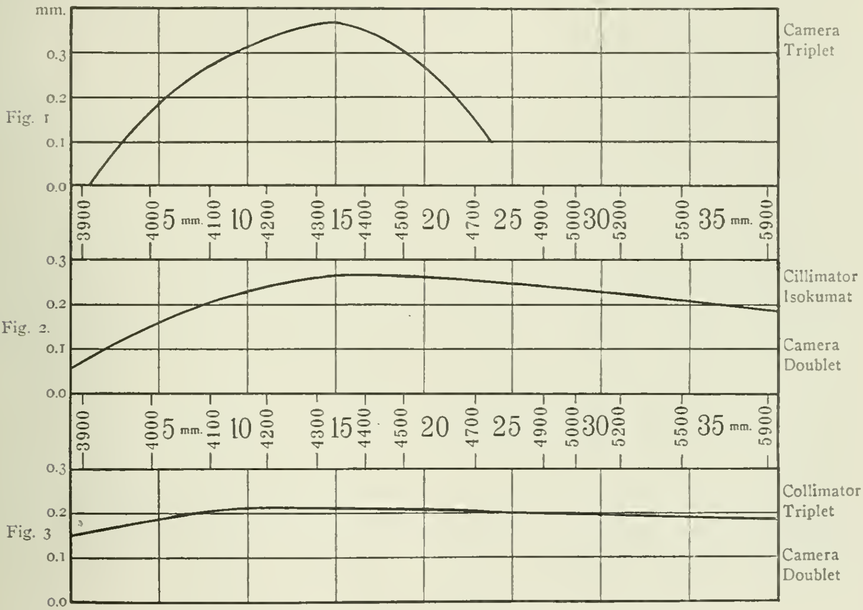

PLATE VIII. FOCAL CURVES.

deviation settings for greater wave-lengths. And for any collimator setting, the Hβ minimum deviation gives a curve as flat as or flatter than the others for that collimator setting. But any one of the three collimator settings seems to give equally good curves in connection with Hβ minimum deviation.

In the more important case, a given range of wave lengths of least deviation from a straight line, is required. And it may be seen at once that the deviation of the focal curves from the plate viation in the ultra violet. Furthermore, for all these curves the definition at focus seems about equally good on all plates, being free from aberration as far as the spectrum is registered.

The focal curve for a collimator setting at the Hβ focus with the prism adjusted for minimum deviation at Hβ is shown in detail in Fig. 2, Plate VIII. The upper curve, on the same scale, is that of a Hasting's triplet in combination with a collimator doublet, all corrected for Hγ light.

In actual practice I have used a collimator

length one sixty-fourth of an inch shorter than the focal distance for Hβ light, have set the prism at minimum deviation for light of wave length, λ 4500 Å, and have inclined the plate surface to cover a range of spectrum in sharp focus from λ 3900 to λ 6000.

NEW COLLIMATOR LENS.

As soon as spectrograms of B and A type stars could be made with these optical parts it was noted that the K region in these spectra required for its clear portrayal about twice the exposure used for the region about λ 4500. This unequal absorption could be attributed in part to the collimator isokumat, and since the use of the Hastings triplet as a collimator lens in combination with the single material doublet promised improved absorption conditions and possibly a flatter focal curve, a new Hastings triplet was immediately ordered and was substituted for the collimator Isokumat in May of this year.

The new collimator lens has essentially the same dimensions as the old one and is corrected for the same spectral region. In both directions in which improvement was hoped for the results have been satisfactory. In the region of the spectrum above λ 4500 the new lens is noticeably more transparent. At the K line the new combination transmits about fifty per cent more light than the old one. The improved flatness of the focal curve with the new combination is particularly striking. Indeed the variation of the focal curve from perfect flatness under these circumstances is so slight that measurement of this deviation becomes quite difficult. In Fig. 3, Plate VIII, the focal curve depending on three independent determinations is drawn in parallel with the curves noted above. As in the case of the combination of Isokumat and Single Material Doublet the minimum deviation is set for λ 4500 and the collimator is a little shorter than the focus for Hβ light. Whereas with the combination of Isokumat collimator lens and single material doublet the deviation of the focal curve between λ 3700 and λ 5900 from a plane plate surface is nowhere greater than 0.07 mm., with the *new* combination this deviation is nowhere greater than 0.025 mm. and from λ 4200 to λ 5900 no certain deviation of the focal curve from flatness can be observed even on the large scale here employed. At the same time the focus is sharp and no trace of aberration in the comparison lines is observable even at the edges of the plate over the region examined from λ 3700 to λ 6000.

It would seem that the use of these optical parts is a step in advance, since they not only increase the available field over that given by other combinations but they should eliminate the errors known to arise from wings, associated with comparison lines, caused by spherical aberration when inferior camera lenses are employed.

EFFICIENCY CONSTANTS OF THE OPTICAL SYSTEM.

The constants defining the efficiency of the optical system of this spectograph are contained in the accompanying table. The purity and difference in wave length just resolved are based on Schuster's old formula for a slit width of 0.025 mm.

EFFICIENCY CONSTANTS OF THE OPTICAL SYSTEM.

CONSTANTS WAVE-LENGTH	RESOLVING POWER	PURITY	dλ RESOLVED	LINEAR DISPERSION t.m. per mm.	EQUIVALENT OF 0.001 MM. DISPLACEMENT
4000 Å	27,000	6,100	0.66 Å	26.7 Å	2.00 KM.
4500 Å	16,000	5,700	0.79 Å	44.1 Å	2.94 KM.
5000 Å	11,000	2,900	1.73 Å	65.2 Å	3.91 KM.
6000 Å	5,400	1,600	3.7– Å	133 Å	6.6– KM.

MECHANICAL PARTS.

In the design of the mechanical parts of this spectrograph especial effort was made to secure two of the desirable features in the moving spectrograph as mentioned above; viz., invariability of position and sharp definition of the spectral features on the photographic plate during exposures. And in this connection errors arising from flexure and temperature change were kept more particularly in view.

The considerations arising from flexure variations which dictated the form and material employed are summarized here.

1. The portion of the spectrograph carrying the slit, optical parts and plateholder should be as rigid as limitations of weight may permit. Local flexure at important points should be carefully guarded against.

2. This portion of the spectrograph (spectrograph proper) should be so supported that its flexures in the plane of dispersion will be compensatory and leave the position of any spectral line on the plate undisturbed with changing position of the telescope.

3. Flexures of the supporting system of the spectrograph should not be communicated to the portion of the instrument carrying the optical parts, slit-head and plate holder.

4. This supporting truss should maintain the spectrograph in position behind the telescope without sensible variation (0.01 inch at the collimator lens) in position relative to the telescope.

The considerations affecting the form and material employed and arising from temperature changes in the apparatus are as follows:

1. The supporting system of the spectrograph should be free to expand or contract with changing temperature without placing the spectrograph box under stress.

2. The spectrograph proper should be attached to the telescope in such a way as to permit a minimum flow of heat from the box to the support or *vice-versa*.

3. The support should join the spectrograph as far from the optical parts as practicable.

4. The portion of the box carrying the optical parts, slit-head and plate holder should be made of homogeneous material, so that with temperature change its form will remain unchanged. No thermal couples should be permitted.

5. This homogeneous material of which the spectrograph proper is made should be a good conductor of heat, in order to distribute quickly any local changes of temperature.

6. If possible the material of which the spectrograph proper is made should be such that its expansion and contraction with temperature change will counteract the changes in the focal distance of the lenses due to temperature variations.

7. A temperature case with efficient heat control should enclose the spectrograph proper as conveniently as possible. This case should be large enough to permit free circulation of air within and should be provided with some means to prevent stratification of air of different temperatures about the instrument.

Nearly all of the above considerations point toward an instrument of the type invented by Wright and adapted to single prism construction at the Allegheny Observatory. Considerations 2 and 3 under flexure can not be secured with the single prism spectrograph of cantilever type, and the isolation of temperature effects in the spectrograph proper as well as the insulation of this essential part of the instrument against temperature change are problems greatly simplified in the spectrograph of the simple beam type.

A brief description of the mechanical parts of the single-prism spectrograph of this Observatory is perhaps essential in order to define the character of the new features introduced. In connection with the illustrations of Plates VI and IX but few words are necessary to convey an adequate idea.

THE SPECTROGRAPH BOX.

For the purpose of description this instrument may be considered as made up of two parts, the spectrograph box and the supporting system, which are mechanically separable and which perform very different functions in the construction. The former carries the slit-head, optical parts and photographic plate in their proper relative positions; the latter supports the spectrograph box in its proper position with reference to the telescope.

The spectrograph box is a triangular skeleton beam, three and one-fourth inches wide, with sides, twenty-three, twenty-eight, and forty inches in length, and one-quarter inches thick. The internal members of the beam vary in thickness from three-sixteenths of an inch to one-fourth of an inch and in length according to their position in the construction. The slit-head is placed of the truss are then distributed so as to secure great rigidity, especially about the optical parts and points of attachment, and are so designed as to support the lenses, slit-head and plate receptacle and to make provision against all stresses that may arise in any working position of telescope. In Plate IX where the distribution of the members of the beam is shown it will be seen

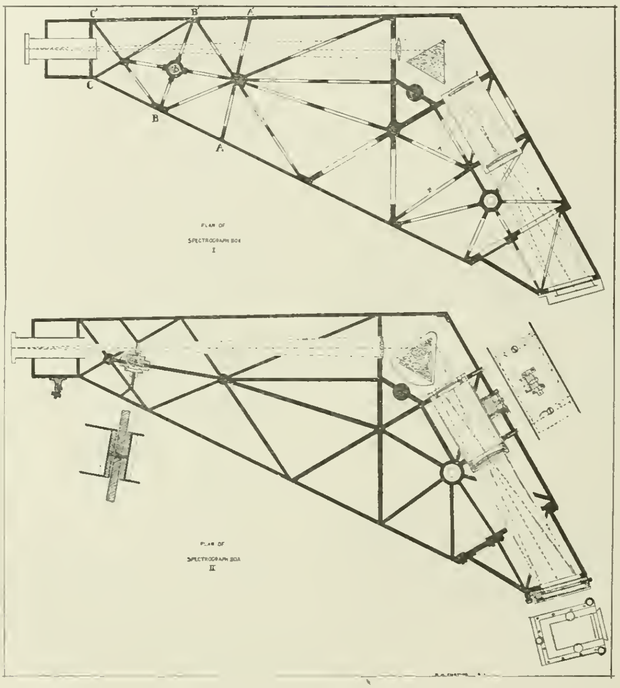

PLATE IX. PLANS OF SPECTROGRAPH BOX.

at the more acute angle of the triangle, the prism with collimator and camera lenses at the obtuse angle, and the plate holder at the remaining vertex, the plane of dispersion containing the axes of the lenses being half way between the two triangular faces of the beam. The two supports or points of attachment are placed approximately in the bisectors of the acute angles of the triangle, each about the same distance (eleven inches) from the nearest vertex. The internal members that the element of strength is carried to its logical limit and that the spectrograph box as constructed ought to satisfy all demands of internal rigidity. However, further resistance to stress is incidentally obtained by two plates, one-sixteenth inches in thickness, which cover the triangular or open faces of the box and which are fastened by numerous screws to the outer and internal members of the beam.

It will be noted that the spectrograph box is

not a unit, however. A section near the plate holder is made removable to make possible the use of a camera lens of twelve inches focus, but the reinforcement of the box at the junction of the added section with the box proper undoubtedly overcomes any weakening of the construction at this point.

The materials of which this box is constructed are brass and bronze exclusively. It was originally stipulated that the spectrograph should be made entirely of brass, in order that expansion and contraction with a given temperature change might be equal in every part, and also in order that heat conduction to equalize any local changes of temperature might be very rapid. Also it was expected that the use of brass in connection with the optical parts would compensate for changes of the focal plane with temperature change, an expectation which has been fully realized. However, on a suggestion of the J. A. Brashear Company that the use of certain bronze castings would facilitate their work, it was decided to depart thus slightly from our original plan, since the constants of bronze are so closely similar to those of brass. Accordingly that section of the internal frame work of the skeleton beam inclusive of the member which supports the collimator lens and extending to the removable section near the plate holder was made of cast bronze and was fitted with duplicated peripheral members into the construction. In this bronze casting all the optical parts including the prism are mounted and the main support of the spectrograph is attached. Another small bronze casting at the slit-head supports the slit-head tube, and a third bronze casting was introduced in our shops to secure great rigidity about the second or upper support of the box.

In the spectrograph box, the plate holder, optical parts and slit-head are mounted without the use of the conventional collimator and camera tubes. The collimator lens, with appropriate opposing screws for adjustment of the axis of the lens, is mounted directly on an internal member of the box, the member forming one of the sides of the prism box. The prism mounting, adapted from that of Keeler, is supported upon a face of the prism box perpendicular to the refracting edge of the prism and forming a part of the extensive bronze casting above described. The camera lenses in their cylindrical cell, five inches in length, and three inches in diameter, are also supported by two parallel members of this casting, in which motion of the lenses for focal adjustment is secured by a nut and screw of thirty threads to the inch, readily accessible on the exterior of the spectrograph box and permitting adjustment of the length of the camera with an accuracy of about one-onethousandth of an inch. A scale with an indicator registers full turns of the screw. The plate receptacle of conventional type but with heavy base plate is attached with opposing screws to the spectrograph box, on a face matching the base plate and making a suitable angle with the axis of the camera lens. The opposing screws permit the final adjustment of the plate surface to follow the focal plane of the single material doublet. The slit-head is carried upon a bronze tube supported by two parallel members of the spectrograph box, four inches apart. A shoe, half way between these supports, clamps the tube firmly in position. The length of the collimator and the orientation of the slit are varied by sliding and rotating this tube without the aid of rack and pinion or any other mechanical device.

FLEXURE AND DISTRIBUTION OF SUPPORTS.

(This section is taken from a paper read in August, 1909, at a meeting of the Astronomical and Astrophysical Society of America).

In the case of the single-prism spectrograph there is known to be considerable danger of error arising from internal flexure. Whatever displacement is present becomes of greater importance in the low dispersion spectrograph because of its greater value in equivalent velocity. It is therefore unfortunate that this form of instrument is especially liable to error of this kind.

The prevailing type of single-prism spectrograph which was evolved from the old visual spectroscope is essentially a cantilever beam with the slit near the plane of support, the plateholder farthest away where flexure deflection is a maximum and the optical system in an intermediate position. From the well known properties of a cantilever beam it is obvious that relative deflections of the plate and optical system of a one

prism instrument as referred to the slit may cause considerable displacement of spectral lines when the position of the spectrograph is changed. To be sure frequent introduction of the comparison will minify the error arising from differential flexure but since a star's image varies in intensity with zenith distance and also since flexure displacement is not a linear function of the hour angle, it can hardly be safe to assume that all appreciable error is eliminated in this way. And in view of the surprisingly large flexure displacements of 80 to 100 km. per second noted by some observers between two positions of spectrographs of the cantilever type, there seems to be a condition here that has needed attention.

The actual flexure displacements of lines from their mean positions in the direction of velocity shift on the spectrogram will in general follow a complex law difficult to predict. A valuable approximation may be obtained however, if we assume the simple sine formula and apply it to the case of the moving spectrograph attached to the eye end of an equatorial telescope, the plane of dispersion in accordance with common usage being coincident with the plane of the hour circle of the observed object. Flexure of the prism through faulty mounting is not considered here since such errors can be eliminated in any type of spectrograph. We assume then that the displacement of any line from its mean position is the product of the maximum flexure and the factors necessary to project the weight of each differential mass across a line which is vertical when the flexure is zero. Since the spectrograph is not in general a symmetrical beam with reference to any flexure axis or line of support the simple sine law will not express the flexure rigidly, though such an elementary representation of flexure and displacement is of interest and value.

Adopting as the normal position for any spectral line the mean of all positions it may occupy when the spectrograph is rotated through 360° in the meridian we may define :

F, The flexure displacement of any spectral element from its mean position in the direction of velocity shift. Positive displacement toward the red.

F_m, The maximum value of "*F*" on the meridian when the telescope is east pointing north of the zenith.

Axis of flexure, A line through the slit in the plane of dispersion of the spectrograph; vertical when $F =$ Zero and approximately horizontal when $F = F_m$.

α, The angle between the axis of flexure and the axis of the telescope or collimator; in other words, α is the zenith distance of the observed object when $F = O$ on the meridian. α is positive when the declination of the intersection of the axis of flexure with the celestial sphere is greater than that of the observed object.

A, The intersection of the axis of flexure with the celestial sphere.

Z, The zenith of distance of A.

Q, The parallactic angle of the telescope pointing.

t, The hour angle of the telescope pointing.

δ, The declination of the telescope pointing.

ϕ, The observers latitude.

For the simple case of a meridian object we may write

$$F = \pm F_m \sin Z = \pm F_m \sin\ (\delta - \phi + \alpha)$$

where the last upper and lower signs refer to telescope east and west respectively. In the general case of an object with coordinates, t and δ, the weight of each differential mass producing flexure must be projected into the plane of dispersion and perpendicular to the flexure axis. Two functions effect this. Sin *Z* defines the component of the weight normal to the axis of flexure in the vertical plane containing the axis of flexure. The factor, Cos *Q*, projects this component into the plane of dispersion. Thus we may write on the basis of the sine law,

$$F = \pm F_m \sin Z \cos Q,$$

which becomes, since

$$-\cos Q = \frac{\cos(\delta+\alpha)\sin\phi - \sin(\delta+\alpha)\cos\phi\cos t}{\sin Z},$$

$$F = \pm F_m[-\sin\phi\cos(\delta+\alpha) + \cos\phi\sin(\delta+\alpha)\cos t].$$

This equation expresses the actual value of F in any position of the telescope when F_m and α are known. From it we may deduce the variation

in F or the flexure variation for any given star when t changes.

Let $F = F_1$ when $t = t_1$,

and $F = F_2$ when $t = t_2$.

Then

$F_2 - F_1 = \pm F_m \cos\phi \sin(\delta + \alpha) [\cos t_2 - \cos t_1]$

where the upper and lower signs refer to telescope east and west respectively.

From this simple equation expressing the variation of flexure displacement in the direction of velocity shift with hour angle, some interesting deductions can be made as follows:

1. For any object the variation of flexure displacement is always smallest at or near the meridian.
2. Flexure displacement for any star is the same in magnitude and direction at hour angles symmetrical with respect to the meridian unless the telescope be reversed.
3. For any object and spectrograph, flexure variation is proportional to cos ϕ. Hence it is zero at the poles and a maximum at the equator. Higher latitudes are advantageous in this respect.
4. For any object for which $\delta = -\alpha$ flexure variation with hour angle is always zero. When $\delta = \pm \pi/2 - \alpha$ flexure variation with changing hour angle becomes a maximum in any given latitude and the expression above becomes

   $F_2 - F_1 = \pm F_m \cos\phi [\cos t_2 - \cos t_1]$.

   Since α reverses its sign when the telescope is reversed over the pier there must be two declination circles distant α from the equator on which there is no flexure variation and two others distant α from the poles on which flexure variation is a maximum. For the single prism instrument for which α is about twenty-five degrees the regions of smallest differential flexures are at $\pm 25°$ declination and the regions of greatest differential flexure are at $\pm 60°$ to $\pm 70°$ declination.
5. If $\phi = -\alpha$, flexure variation becomes zero for objects crossing the zenith. This condition is therefore advantageous.

The flexure constants, F_m and α, depend upon the weight, coefficient of elasticity and distribution of materials in the spectrograph box including the slit, optical parts and plateholder. In the case of the single prism instrument, neglecting flexure of the prism mounting, the axis of flexure will probably follow closely a straight line joining the slit and its image in the camera, but in general a few measures of flexure in the meridian will be necessary to determine α and F_m and to discover the law of variation of flexure with zenith distance in case the sine law assumed here is inapplicable.

The values of F_m, α and ϕ furnish criteria bearing upon the freedom from flexure of any given moving spectrograph. If the instrument be mounted with slit east and west and attached to an equatorial telescope, on the basis of the sine law the best flexure conditions obtain when F_m is small, and ϕ, large and when α is the negative of ϕ.

The greatest flexure variation is one hour's exposure will occur when $\delta = \mp \pi/2 - \alpha$ at an hour angle of ± 6 hrs. In this case in latitudes of 40° the differential flexure will amount to one fifth of the maximum flexure on the meridian. Since for the single prism spectrograph this value of δ may be in the neighborhood of 65° such an exposure is quite possible. An exposure of three hours in the same part of the sky would lead to a differential flexure slightly greater than one-half of the maximum flexure in the meridian. These results are in accordance with measures by Küstner who found in his 3-prism spectrograph a flexure of 75 km. per sec. at Hγ on the meridian and a flexure displacement of 12 kms. per sec. in an exposure of one hour in his least favorable region of the sky. In the case of single prism spectrographs of the cantilever type with flexures of 50 to 100 kms per sec. in the meridian, an exposure of three hours may entail a flexure of 25 to 50 kms. per second for any given spectral element during the exposure.

With these and other considerations in mind, several single-prism instruments of the simple beam type have recently been constructed. In this simple beam type of instrument flexure can be practically eliminated or made compensatory by suitably placing the supporting points or by the introduction of counterbalancing levers. The latter method was actually tried by the writer in the summer of 1906 in order to demonstrate that the displacements in the Mellon spectograph,

which he was then investigating, were really flexure displacements and that they could be eliminated by a moderate counter force opposing gravity at the plateholder. Later a plan embodying this method of flexure elimination was drawn up in detail for the new Detroit Observatory spectrograph. It has also been developed independently by Mr. Plaskett. The idea was finally rejected here however, in favor of the method of suitable distribution of two supporting points. The two sketches of Plate IX show sections in the plane of dispersion of two forms of spectrograph box each being about 3⅜″ deep and otherwise of similar dimensions. In each case the support near the prism is considered fixed in position and is a ball and socket joint. The upper support is to be determined by trial so that flexure between and outside of the supports will be compensatory. In the sketches I have indicated my predicted positions for the upper support near the slit but when the instrument was ordered from the J. A. Brashear Company it was stipulated that the upper support should be omitted entirely from the construction. Plan I, in which the adopted support is nearer the plate holder, was selected because it gave promise of a better position for the upper support and also because it was desirable to keep this communication with the metal parts outside of the temperature case as far from the optical parts as possible.

In determining the flexure of this instrument three pairs of points (AA′, BB′ and CC′, Plate IX, Fig. 1) were adopted for the upper supports. For each pair of points three exposures of comparison spectra side by side were made always with the plane of dispersion vertical and the longest side of the triangle horizontal but in the first and third exposure with the prism below and in the second exposure, which was between the other two on the negative, with the prism above. Thus apparently the double flexure or twice the so-called maximum flexure was measured in each case. The results follow.

SUPPORT	DOUBLE FLEXURE	DOUBLE FLEXURE IN KM. PER SEC. AT $H\gamma$
AA′	— 2.24 microns	— 6.3 KM.
BB′	— 0.52 microns	— 1.4 KM.
CC′	+ 1.39 microns	+ 3.9 KM.

It is thus evident if the sine law holds and if the position of the axis of flexure has been properly chosen that the point of support for zero flexure should be about one fourth the distance from BB′ to CC′ on the basis of these measures. However for symmetry of construction and because it is planned to remove a section of the box at the plate holder to permit the use of a twelve-inch camera objective instead of the sixteen-inch, it was decided to adopt the position for the upper support as shown in the sketch. This position should give flexures nearly equal and opposite for the twelve-inch and sixteen-inch cameras.

For the sixteen-inch camera the flexure has been determined with the upper support in place. The maximum flexure determined as before proves to be — 0.45 microns, the equivalent of — 1.3 km. per sec. at $H\gamma$. In an exposure of three hours in the least favorable region of the sky the change of position of the $H\gamma$ line due to differential flexure of the spectrograph box should be not greater than 0.6 kms. per sec. or about 0.00023 mms. In one hour this displacement of $H\gamma$ should not exceed 0.3 kms. in the least favourable region of the sky. These results have been obtained without temperature control and are also affected by flexure of the prism mounting. It is nevertheless clear that differential flexure is vanishingly small in this instrument as it stands; and there is good reason to expect that the same condition will obtain when the 12″ camera is employed, though the requirements will be even more exacting.

THE CHARACTER OF THE SUPPORTS.

The lower support of the spectrograph box is a steel ball, turned up at the center of a steel shaft, which is roughly in the shape of a double cone, with the bases of the cones against the ball. The steel ball fits snugly into small zonal bearings in the spectrograph box, one of which is adjustable, the two forming a socket for the ball with its center in the plane of dispersion of the spectrograph. The ends of this shaft and of the two others mentioned below, all of which are normal to the plane of dispersion, are securely bolted to the supporting cradle described below. For the upper support near the slit-head, a second steel shaft tapering from the middle toward each end

is connected with the spectrograph box by a gymbal joint, consisting of two pins or solid cylinders crossing at right angles, and each passing normally through the center of the shaft. The larger pin or cylinder passes through a slot in the steel supporting axle into which it is fastened by the second pin which also serves as a bearing about which the larger pin may rotate. This larger steel cylinder is mounted with its axis in the line joining the two supports and fits at either end into cylindrical bronze bearings in the spectrograph box in the plane of dispersion. In these bearings the steel cylinder may rotate or slide longitudinally, thus permitting automatic adjustment of the distance between supports with temperature change and giving all the freedom of a ball and socket joint. The two supports acting together cannot cramp the box in any manner; but the combined restriction of these two supports leaves the box free to rotate about an axis joining them. Accordingly a steel shaft, passing through the open frame not far from the prism box carries two small guides, which may be adjusted to bear against two opposite points especially reinforced in the triangular sides of the spectrograph box. In Plate IX, the bearing point of the guide on one face of the box is easily located at the center of the black circle near the base of the prism. When the plane of dispersion is vertical the guides carry no weight, and the spectrograph box is resting entirely upon its supports. In any other position one of the guides carries a fraction of the weight of the box.

In the above system of support the cross section of metal across which heat may be conducted from the spectrograph box to the supporting cradle is a minimum. The two zonal bearings at the lower support have a combined area of approximately one-eighth of a square inch. The upper support is connected with the spectrograph by a three-sixteenths-inch pin only, and the guides are practically points bearing upon a very small area. Very little temperature conduction occurs at these points.

Finally, this system of attachment of the box to the supporting cradle has been found most convenient in effecting the adjustment of the instrument with reference to the telescope.

THE SUPPORTING CRADLE.

The supporting system is similar to that used at the Lick Observatory in connection with the new Mills Spectrograph; but considerable modification has been introduced to provide for the support of the three steel shafts and the guiding microscope. The general form of this part of the instrument is well shown in Plate VI, but may be briefly described.

A rigid cast iron ring bolted securely to the spider of the focussing mechanism of the telescope carries four symmetrical bosses, the chord joining each pair of which is parallel to the plane of dispersion at a distance of six and a half inches. To the face of each of these bosses is fastened a two- by two-inch T-beam. Each pair of these beams which is in a plane parallel to the plane of dispersion, converges to a stiff bronze casting, which supports one end of each of the two lower transverse axes. A well braced cross piece of cast iron connecting each pair of T-beams at a suitable point furnishes support for the end of the steel axis of the upper support. The three steel shafts together with the supports of the guiding telescope furnish a rigid connection between the two pairs of T-beams forming the truss. An additional element of rigidity at right angles to the plane of dispersion is furnished by a fifth T-beam, supported like the others on a boss on the ring casting but as far as possible from the plane of dispersion and converging to the bronze casting supporting the end of the steel shaft of the lower spectrograph support, on the side farthest from the polar axis of the telescope.

This supporting cradle is found to be rigid enough to support the spectrograph box, with temperature case, all together about one hundred and fifty pounds, with a negligible flexure effect.

THE SLIT-HEAD.

The slit-head is patterned after that of Keeler's Allegheny Spectrograph of 1893, with the usual reflecting slit jaws first used by Huggins. The following modifications, in addition to the totally reflecting prisms and prism mountings of the comparison, have been introduced:

Adjustable stops have been provided to prevent absolute closure of the slit jaws, thus protecting

the edges of the slit from damaging pressure and making possible the use of a slit with very sharp edges. The microscope behind the slit carries only a totally reflecting prism and a lens. The image of the slit may be observed with or without an eye-piece at a convenient point near the guiding microscope. The use of a long tube is thus avoided.

COMPARISON APPARATUS.

The spark comparison apparatus is modelled after that devised by Wright for the Mills spectrograph. However, instead of single pairs of terminals, two drums, as used by Frost, are employed, each carrying six sets of points. It is thus possible to bring fresh terminals into play, in case the pair in use fails to perform. Cylinders of the elements used for the spark are ground and pointed in our own shop, and are mounted in a manner calculated to facilitate adjustment. The coil, capacity, and self inductance are mounted on the telescope near the slit head, thus avoiding the inconvenience of carrying a high potential circuit across the floor, or on the pier and telescope axes.

The element used in the spark during the first year was titanium, partly because the activity of this element in the spark was of advantage in connection with the smaller coil then in use. With the purchase of a larger coil experiments were made with various elements and alloys, including iron, titanium, chromium, manganese, copper, nickel, lead, silver, cobalt, bismuth, alloys of iron with titanium, manganese, chromium, silicon, vanadium, molybdenum, and other miscellaneous combinations. Titanium proves to be the best single element, notwithstanding its weak regions in the neighborhood of λ 4200 and λ 3850. With plates sensitized up to λ 6300 it is also as good as any element that I have tested. Some of the alloys tested furnish a better distribution of lines, and the best among these are combinations of equal parts of iron and titanium, iron and chromium, and iron and molybdenum, with relative merit in the order given. For red sensitive plates a thin stain of filter yellow K on the ground glass mat between the comparison source and slit proves useful in bringing out comparison lines in the yellow, orange and red regions of the spectrum.

The frequent introduction of the comparison light, so easily effected with this type of comparison apparatus, distributes the exposures upon the reference lines throughout the exposure on the star and makes possible necessary allowance for interference by passing clouds. It is our practice to introduce the comparison spectrum at intervals of one minute for exposures of less than ten minutes; at intervals of not more than two minutes for exposures of not more than thirty minutes duration; at intervals of not more than five minutes for exposures of an hour or less; and at intervals of not more than ten minutes for exposures of greater duration than one hour.

GUIDING MICROSCOPE.

The guiding microscope, mounted with its axis in the plane of dispersion of the spectrograph, extends out on the side away from the plate holder. A small forty-five degree prism, three inches above the slit-head, reflects the star's light from the inclined speculum slit jaws into a small microscopic objective, which brings both slit and star image to a focus in the same plane before a direct vision eye-piece. A prismatic eye-piece may be substituted for the direct vision ocular at the observer's convenience. This simple guiding microscope has been adopted in preference to more convenient forms involving loss of light, in order to economize light in the observation of faint stars. For the observation of stars at considerable zenith distance an ethyl violet screen is inserted in front of the eye-piece, cutting out the green and yellow rays and revealing the star's blue light as displaced by atmospheric dispersion.

TEMPERATURE CASE.

The temperature case of the type used by Campbell, encloses the whole spectrograph box, including the slit-head. The main compartment includes the box up to the slit-head and comparison drum. A second small compartment covers the slit-head and comparison drums, with a small aperture to admit the star's light. The external layer of the temperature case is of one-half inch enameled pine. Inside of this is a 3/8-inch layer of waste, then 1-16 inches of wood fiber, and inside of this in the case of the main compartment a 1/4-inch air space and a second 1-16-inch layer of wood fiber enclose the air space of 1 1/2 inches

about the spectrograph box. In addition a heavy felt jacket is buttoned over the brass spectrograph box as a further insulation against local heating. Distributed uniformly over the interior of the main compartment of the temperature case is a heating circuit, comprising one hundred and thirty-eight feet of No. 27 German silver wire, strung at intervals of approximately an inch. The heating current, which rises to a maximum of three fourths of an ampere, is regulated by a mercurial thermostat with its bulb mounted on the outside of the spectrograph box near the prism. The bulb of the thermostat has an internal diameter of one fourth of an inch and is eight inches long. The capillary is one fiftieth of an inch in diameter and ten inches long and is open at the top. This instrument proves very efficient. After a little experience the observer at the beginning of the night can set the movable platinum wire which completes the themostat circuit near the top of the mercury column, and this adjustment needs no further attention during the night.

A small fan motor mounted in the upper part of the main compartment of the temperature case serves to produce circulation of air. This motor is governed by a battery rheostat on the outside of the temperature case near the observer.

Two thermometers graduated to tenths of a degree Centigrade are mounted in parallel with the stem of the thermostat. The bulbs of these thermometers are mounted as near as possible to the prism, one outside and the other inside of the prism box. The stems of all these thermal instruments are viewed through a long window of double glass cut in the side of the temperature case.

The smaller compartment of the temperature case about the slit-head is readily removed. The main compartment divides into three sections, one of which covers the plate holder and the lower end of the spectrograph. This section of the box is also easily removed to permit examination of the collimation of the spectrograph as well as visual observation of spectra. The remainder of the main compartment of the temperature case divides along the lines joining the supporting shafts of the spectrograph and on these shafts the temperature case is supported.

AUXILIARY APPARATUS.

OUTSIDE TEMPERATURE CASE.

The large temperature case, designed by the writer and described else where in this volume, encloses the spectrograph during the day and facilitates greatly the control of temperature about this instrument. At night when work is begun the temperature inside of the spectrograph temperature case, which is not removed or opened for airing, is usually a degree or so above the outside temperature and the prism is kept at essentially the same temperature throughout the day and night. Thus satisfactory temperature conditions are obtained without exposing the spectroscope to dust and air.

MEASURING ENGINE.

The measuring engine is well shown in Plate X. It was designed by the writer and was constructed by the J. A. Brashear Company. It combines the better features of the Toepfer and Gaertner engines and represents a compromise between the light construction of the former and the massive design of the latter type.

The more important new features embodied in the design of this engine may be briefly enumerated. The back-lash of the screw is taken up by a spiral clock spring mounted at the end of the bed of the engine. The secondary plate carriage may be moved by hand into any position and may be taken out and reversed to reverse the plate for the elimination of personal equation error. A pair of mirrors reflect the micrometer and index into the observer's right eye thus obviating the necessity of averting the eyes and head to read each setting of the plate carriage. Provision is made for the rotation of the microscope about an axis parallel with the axis of the screw. This makes it possible to secure small adjustment of the spectrum up and down in the field and is of convenience especially in connection with the interrupted reticle. The reticle holder is made removable to permit of the use of several types of reference lines in the ocular field.

Of the various reticles used, the single vertical line interrupted at the star spectrum has proven most satisfactory. In the preparation of such reticles on glass some experience has been gained

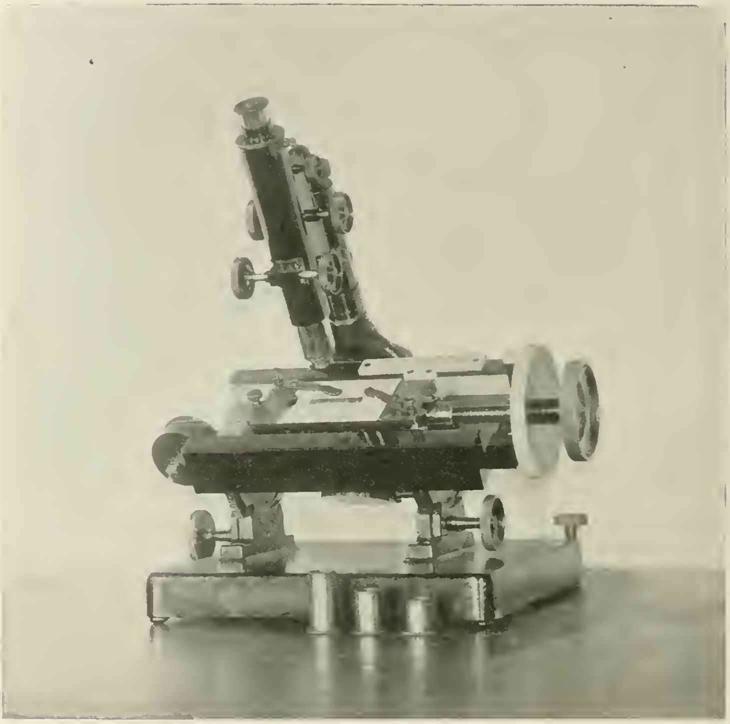

PLATE X. MEASURING ENGINE NO. I.

which may be of use to others. Four methods were tried all of which could doubtless be made successful. These methods include etching with hydrofluoric acid, ruling with a diamond point, photographic reduction from a drawing in black and white and direct photography of comparison lines with the spectrograph itself. The first method was used by the J. A. Brashear Company but nothing usable was obtained. Many ruled reticles were made by the writer upon crystal cover glass using the moving table of a milling machine to space the lines and the interruption. These reticles were very successful, the sharp black ruling proving if anything too fine for use with a one inch eye-piece. However, because of the slight optical effects at the edge of such rulings on glass futher experiments were made with the photographic method.

As no suitable photographic apparatus was available attempts to reduce a drawing on paper were not successful, though undoubtedly this method will give good results. The interrupted reticles which we are using were made according to the fourth method noted above. With a very narrow and long slit the comparison spectrum was exposed in the usual manner upon a plate of the finest grain. From this spectrogram of the comparison reticles were cut out with a glass cutter and mounted in the microscope reticle holder with some well defined sharp line in the center of the field. The length of the interruption in this line was controlled by the usual diaphragms in front of the spectroscope slit and may be made of any desired length. Several reticles were made, suitable for use with different powers. Thus with the spectrograph itself permanent reticles were prepared with which settings on the star lines can be made with an accuracy not inferior to that obtained with the spider thread. And in addition the advantage is secured of full visibility of the line while the setting is being made. Especially in the case of narrow sharp lines is this consideration important.

The screw of this measuring engine, developed by our own Instrument Maker, Mr. H. J. Colliau, seems to possess a remarkable accuracy. The pitch is one-half of a millimeter, and a movement of the plate carriage of three and one-fourth inches is provided for. Studies of the periodic error indicate that in this respect this screw compares favorably with the best screws that are in use in engines of this type. The correction formulae, to be applied in kilometers per second to any reading at $H\gamma$ for our spectrograph as well as the value of a given interval on three well distributed sections of the screw are given in the accompanying table, where "A" is the position angle of the micrometer head measured from a cross point of the error curve.

Section of Screw	20 R — 30 R	80 R — 90 R	150 R — 160 R
Correction Formula	+ 0.14 KM sin A	+ 0.04 KM sin A	— 0.15 KM sin A
Value of the distance between reference points	0.53479 R	0.53471 R	0.53483 R

It will be noted that there is a progressive change in the correction formula along the screw, and this led to a suspicion that the ways of the engine were convex or concave. This was investigated with a dial micrometer in combination with our milling machine and was found to be the case. But the maximum correction that can ever arise from the periodic error of this screw, even as modified by the inaccuracy of the ways, need not be considered in any work for which the engine was designed or intended.

The measurement, reduction and discussion of the spectrograms obtained with this spectrograph are now being carried on as opportunity permits. Results will appear from time to time in these publications.

June, 1912.

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY FROM AUGUST 16, 1909, TO JANUARY 1, 1912.

By WALTER M. MITCHELL.

The seismological equipment of this observatory was installed during the summer of 1909. The instruments were set up in the month of August in that year, and since that time have been in continuous operation. A description of these instruments has been given elsewhere; as stated there the equipment consists of the following:

Two Strassburg 100 kg. Tromometers by Bosch. These are so mounted that one gives the east and west component of the motion produced by the disturbance, while the other gives the north and south component.

One Wiechert Horizontal Seismograph, with steady mass of 100 kg. by Spindler and Hoyer. This is so mounted that the east and west, and north and south components are recorded.

One Wiechert Vertical Seismograph with steady mass of 80 kg. by Spindler and Hoyer.

The seismograph room (Plate V) is in the basement of the observatory building, the instruments being about 2 meters below the surface of the ground. On account of the situation and contruction of this room its temperature varies but slightly. The average daily variation is less than 3.0° F., occasionally however the variation is as great as 5.5°, but this latter figure is rarely exceeded. All the instruments are mounted on the same pier which is of concrete, approximately rectangular in shape, the dimensions being 3.1 by 3.6 meters; the longest dimensions being east and west. The pier has a depth of 1.3 meters, and is wholly isolated from the rest of the building.

The observatory is situated on the outskirts of the city of Ann Arbor, upon a hill about 1.5 km. in a north-east direction from the center of the city. The surface geological formation of this region is glacial till, consisting of coarse sand and clay with gravel and boulders to a depth of 40 meters or more.

There are two railroads in the vicinity; the tracks of one of these are directly north of the observatory at a distance of about 0.5 km. The vibrations caused by passing trains are distinctly visible on the seismograph records, and at times can easily be confused with microseismic tremors of small intensity. The other railroad is about 1.5 km. distant from the observatory and probably causes no disturbance.

As the observatory is stituated on the outskirts of the city, there are no street car lines in the vicinity and the wagon traffic is a minimum; hence from the point of view of seismology the situation is quite satisfactory.

The following table gives a list of the earthquakes that have been recorded at this observatory during the period from August 1909 to January 1912.

Column I gives the serial number of the shock. Remarks relative to the peculiarities of the shock as recorded follow the table, similar numbers referring to similar shocks.

Column II gives the date on which the shock was recorded.

Column III gives the component, and the instrument with which it was recorded. B-EW and B-NS, indicating the east and west, and north and south components respectively of the Bosch Strassburg Tromometers. Similarly W-EW and W-NS indicate the east and west and north and south components recorded with the Wiechert instrument.

Columns IV, V, VI, VII, VIII, and IX, give the recorded times of the phases of the shock. All times given in this account are Central Standard Time, midnight to midnight; to obtain Greenwich civil time add six hours.

The notation at the heads of these columns is practically that of the Göttinger system, in which,

P—First preliminary tremors.

S—Second preliminary tremors.

L—Long waves. (Principal portion of shock).

M—Greatest motion. (Time of maximum amplitude).

K—End of long waves.

F—End of visible disturbance.

* and † indicate that the beginning of the phase is well defined, or gradual, respectively.

Column X gives the maximum amplitude; that is the greatest excursion of the recording point from the zero line, measured in millimeters.

Column XI gives the mean of the distances in megameters as computed by the Laska formulae.

$\Delta = (S - P - I)$.

$\Delta = 1/3\ (L - P)$.

$\Delta = 1/2\ (L - S + I)$.

When the values of Δ given by these formulae agree, the computed distance has been considered accurate, and is so indicated in the remarks.

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1909		h m	h m	h m	h m	h m	h m	mm.	mgm.
1	Aug. 16	B—EW	1 2.6*	1 8.3	1 14.5†	1 16.3	1 21.7		0.8	4
		B—NS	1 3.9†		1 14.9†					
2	Aug. 31	B—EW	5 52.5*	6 5.9†	6 8.5†	6 9.0	6 10.7	6 25	0.7	3
		B—NS	5 52.4*	6 5.4†	6 9.1†	6 9.3	6 13.0	6 27	0.9	
3	Sept. 8	B—EW	10 58.1	11 5.6	11 15.6	11 19.7	11 20.3	11 47	0.9	6
		B—NS	10 57.1	11 5.8	11 15.9	11 19.8	11 20.7	11 50	0.6	
		W—NS	10 59.4		11 17.0		11 22.0	11 34	0.3	
4	Sept. 19	B—EW			14 41.5†	14 42.7	14 43.5	14 47.0	0.9	
		B—NS			14 42.5†	14 43.3	14 43.9	14 49.2	0.2	
5	Oct. 3	B—EW			14 59.7	15 1.4	15 1.8	15 4.9	0.4	
		B—NS			14 59.7	15 1.3	15 3.8	15 6.3	0.2	
		W—EW			14 59.8		15 3.5			
		W—NS			14 59.9		15 2.0			
6	Oct. 18	B—EW	2 35.2		2 39.3†	2 40.3	2 42.3	2 52	0.5	1.3
		B—NS	2 35.1		2 39.3†	2 40.5	2 41.5	2 56	0.6	
		W—EW			2 39.6*		2 42.2	2 49		
		W—NS	2 33.6		2 38.5*			2 44	0.3	
7	Oct. 20	B—EW			18 33.5†		18 50.8	18 59.4		
		B—NS			18 37.3†		18 53.8	19 1		
8	Oct. 29	B—EW			1 4.6†		1 8.1	1 9		
		B—NS		1 1.7	1 3.3*		1 6.8			
		W—NS		1 2.0	1 3.7		1 5.2	1 11		
9	Oct. 31	B—EW	16 29.1*	16 31.3†	16 35.7*	16 42.8	16 45.1	17 25	3.0	2.1
		B—NS	16 29.2*	16 32.1†	16 35.9*	16 41.9	16 42.5	17 24	2.5	
10	Nov. 10	B—EW			0 39.0†			1 25		
		B—NS			0 35.0†			1 30		
11	Dec. 9	B—EW			10 32.0†		11 3.0		0.5	
		W—EW			10 32.0†		11 1.0			
		W—NS			10 36.5†		10 49.5			
	1910									
12	Jan. 1	B—EW	5 6.9*		5 11.5*	5 16.7	5 39.3	6 19	>100.0	1.5
		B—NS	5 7.2*		5 11.7*	5 24.8			29.0	
		W—EW	5 7.7*		5 11.8*	5 16.5	5 23.8	5 58	8.0	
		W—NS	5 7.3*		5 11.5*	5 20.6	5 32.0	5 56	7.0	

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1910		h m	h m	h m	h m	h m	h m	mm.	mgm.
13	Jan. 22	B—EW	2 55.6	3 1.0	3 9.1†	3 13.3	3 14.8	4 5	50.0	
		W—EW	2 55.0	3 1.6	3 11.5†	3 14.5	3 16.0	3 55	6.0	5.1
		W—NS	2 56.0	3 2.8	3 13.0†	3 15.5	3 17.0	3 52	4.0	
14	Jan. 23	B—EW	12 56.1*	13 2.0*	13 9.8		13 15.3	13 39	2.0	
		B—NS	12 56.4*	13 2.3*	13 10.3		13 17.7	13 30	2.0	4.7
		W—EW	12 55.5*	13 1.5*	13 10.0		13 14.5	13 20	1.0	
		W—NS	12 55.5*	13 1.4*	13 9.5		13 17.0	13 22	1.0	
15	Feb. 28	B—EW	15 14.6†	15 22.7†	15 32.6†	15 33.1	15 33.3	16 5	2.3	
		B—NS	15 15.3†	15 24.1†	15 33.5†	15 34.6	15 34.9	16 4	1.0	6.0
		W—EW		15 25.0	15 33.0	15 33.5	15 34.0	15 47	0.6	
		W—NS		15 25.0	15 33.5	15 34.3	15 35.0	15 57	0.8	
16	Mar. 11	B—EW	1 0.5†		1 8.0		1 15.2		0.1	
		B—NS	1 0.5†		1 8.0		1 15.0		0.2	2.5
		W—NS	1 0.5†		1 8.0		1 14.0		0.3	
17	Mar. 18	B—EW	18 24.8		18 28.2		18 32.2	18 38.0	0.4	
		B—NS	18 24.6		18 27.5	18 28.6	18 30.5	18 38.5	0.7	
18	Mar. 30	B—EW			11 56.5	12 2.0	12 3.3	12 28.3	2.0	
		B—NS			11 54.7		12 3.3	12 21.5	0.2	
		W—EW			11 56.0		12 2.5			
		W—NS			11 54.0		12 2.0	12 10.0	0.1	
19	April 11	B—EW		18 45.1	18 48.3			19 38	1.0	
		B—NS	18 40.9	18 46.8	18 49.9			19 37	1.0	
		W—NS	18 41.0	18 46.8	18 50.0		18 52.0	19 36	0.8	
20	April 26	B—EW	19 38.4	19 41.9	19 44.8		19 46.3	20 4	0.3	2.0
		B—NS	19 38.6		19 45.5		19 45.8	20 4	0.1	
21	May 4	B—EW	18 37.0	18 40.9	18 45.5		18 54.5	19 9	0.5	
		B—NS	18 37.2	18 41.1	18 46.8		18 48.7	19 8	0.6	2.6
		W—EW	18 38.2	18 41.8	18 45.4		18 49.0	18 55	0.2	
		W—NS	18 38.0	18 41.7	18 45.4		18 49.2	18 59	0.3	
22	May 13	B—EW	2 7.8†	2 14.5*	2 24.4*	2 36.0	2 36.3	4 3	5.0	
		B—NS	2 7.5†	2 14.3*	2 24.2*	2 34.0	2 42.0	3 42	3.0	5.7
		W—EW	2 8.3†	2 14.3*	2 24.2*	2 33.3	2 45.0	3 29	2.0	
		W—NS	2 7.0†	2 14.0*	2 24.0*	2 32.5	2 42.0	3 47	1.8	
23	May 20	B—EW	6 16.7*	6 19.9*	6 23.3	6 24.9	6 25.9	6 38	2.0	2.2
		B—NS	6 16.7		6 24.4		6 25.9	6 37	0.5	
24	May 22	B—EW	0 36.4	0 47.0*	1 5.3†		1 18.0	2 00	0.3	
		B—NS	0 36.6*	0 46.7*	1 8.7†		1 25.7	1 33	0.2	10.1
		W—EW	0 36.5	0 46.6	1 5.0		1 22.0	1 31	0.3	
25	May 30	B—EW	23 1.7*	23 6.6	23 13.3	23 26.6	23 27.8	23 57	1.6	
		B—NS	23 1.5*	23 7.0*	23 14.2*	23 20.1	23 27.7	23 58	3.0	3.9
		W—EW	23 1.5*	23 6.4*	23 13.6†	23 26.4	23 28.0	23 50	0.7	
		W—NS	23 1.6*	23 6.4						
26	June 1	B—EW	0 21.5		0 56.9	1 1.0	1 7.0	2 19	0.3	
		B—NS			0 56.0		1 13.0		0.1	
		W—EW			0 57.0	1 0.0	1 2.0	1 57	0.2	
27	June 16	B—EW	0 50.6*		1 0.3	1 1.7	1 40.3	3 13	10.0	
		B—NS			1 0.0	1 22.6	1 25.7	3 9	1.0	3.1
		W—EW	0 50.4*		1 0.0	1 0.4	1 41.0	3 5	2.5	
28	June 29	B—EW			2 46.3		3 10.4	3 21	0.2	
		B—NS			2 46.7		3 10.7		0.1	
29	June 29	B—EW			5 43.1	5 53.4	5 54.7	6 39	0.9	
		B—NS			5 42.7		6 3.7	6 19	0.1	
		W—EW			5 43.0		5 46.0	6 2	0.1	

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1910		h m	h m	h m	h m	h m	h m	mm.	mgm.
30	July 3	B—EW			3 26.3		3 32.9	3 38	0.2	
		B—NS			3 26.0		3 33.7	3 39	0.1	
31	July 6	B—EW	22 55.3	22 57.3	22 58.6	22 59.3	22 59.8	23 20	16.0	1.3
		B—NS	22 54.5	22 57.4	22 58.7	22 59.1	22 59.4	23 21	5.0	
		W—EW	22 55.1	22 57.1	22 59.9	22 59.0	23 0.0	23 9	4.0	
		W—NS		22 57.1	22 57.7	22 58.0	22 58.3	23 4	3.0	
32	July 17	B—EW	4 11.9	4 14.3	4 16.8		4 18.7	4 33	0.6	
		B—NS			4 16.1		4 18.7	4 30	0.7	
33	Aug. 4	B—EW	19 38.0*	19 45.3†	19 50.3	19 51.7	19 53.3	20 42	4.0	3.8
		B—NS	19 38.0	19 42.7†	19 48.7	19 49.2	19 52.2	20 26	7.0	
		W—NS			19 48.5	19 49.0	19 53.0	19 59	3.2	
34	Aug. 11	B—EW	10 36.5	10 41.0	10 44.8	10 45.6	10 45.9	11 8	7.0	2.9
		B—NS	10 36.1	10 40.5	10 44.3	10 45.2	10 48.3	11 7	0.5	
		W—EW		10 40.5	10 44.2	10 45.0	10 46.3	10 53	1.3	
		W—NS			10 44.5		10 48.3	10 59	0.2	
35	Aug. 21	B—EW			24 2.9		24 10.4		1.0	
		B—NS	23 55.1		24 3.0		24 8.5	24 30	0.5	
36	Sept. 6	B—EW	14 24.0		14 46.0			15 15	0.1	
37	Sept. 7	B—EW			2 12.0		2 37.0	3 0	0.2	
38	Sept. 7	B—EW			4 57.0		5 30.0		0.2	
39	Sept. 8	B—EW	19 23.9	19 31.9	19 42.4	19 42.5	20 0.0	20 51	4.0	5.5
		B—NS	19 23.9	19 32.1	19 42.0		20 2.0	20 50	0.8	
		W—EW			19 44.8				0.4	
		W—NS	19 23.8	19 32.0	19 42.0		20 0.0	20 40	0.4	
40	Sept. 23	B—EW	21 38.5	21 43.2	21 49.6		22 7	22 50	1.0	3.7
		B—NS	21 38.3	21 43.3	21 49.5		22 1	22 50	0.7	
		W—EW			21 49.1				0.8	
		W—NS	21 38.3	21 42.9	21 49.9		22 6	22 50	0.4	
41	Oct. 4	B—EW	17 10.9		17 19.3	17 20.2	17 21.5	17 42	4.0	2.8
		B—NS	17 11.3		17 19.8	17 20.7	17 22.2	17 52	1.0	
		W—EW			17 19.1	17 21.1	17 21.3	17 24	2.5	
		W—NS	17 10.7		17 19.2	17 20.0	17 21.5	17 43	1.1	
42	Oct. 15	B—EW			20 32.0		20 36.7		0.2	
43	Nov. 6	B—EW	14 37.8†	14 42.3†	14 48.5*	14 49.3	14 52.3	15 37	20.0	3.3
		B—NS	14 37.7†	14 43.0†	14 48.7*	14 52.2	14 54.3	15 42	13.0	
		W—EW	14 37.7†	14 42.9†	14 48.8*	14 53.0	14 53.5	15 15	4.1	
		W—NS	14 38.0†	14 42.1†	14 48.6*	14 52.2	14 54.3	15 33	6.0	
44	Nov. 9	B—EW	0 21.0†	0 31.4†	1 0.4	1 24.8	1 30.3	3 0	1.0	
		B—NS		0 30.7	1 16.8			2 37	0.2	
		W—EW			0 57.2	1 24.8		2 27	0.2	
		W—NS		0 31.8†	1 16.5	1 19.0		2 35	0.1	
45	Nov. 24	B—EW	22 59.0	23 10.4	23 38.7	23 40.2	23 50.2	25 10	2.3	10.2
		B—NS	23 0.1		23 39.1	23 40.6		25 23	0.1	
		B—EW	23 0.3	23 10.6	23 37.0	23 40.0	23 51.1	25 35	2.0	
46	Dec. 10	B—EW			4 26.8	4 28.5	4 32.9	4 56	1.5	
		W—EW			4 25.0	4 28.6	4 32.0	4 58	0.5	
47	Dec. 13	B—EW	6 31.9	6 39.6	6 42.9	6 43.9	6 45.0	7 24	5.0	3.1
		B—NS			6 30.9	6 37.8	6 44.8	7 24	1.1	
		W—EW	6 31.1	6 37.3	6 42.0	6 43.2	6 44.6	7 23	1.5	
		W—NS			6 32.1		6 45.0	7 19	1.0	
48	Dec. 16	B—EW	9 7.3	9 15.9	9 23.1		10 12.3	11 6	0.7	
		B—NS	9 4.7	9 16.2				10 50	0.3	
		W—EW	9 4.3	9 21.4	9 38.0		10 13.0	11 6		
		W—NS	9 4.1		9 56.0		10 30.0			

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1910		h m	h m	h m	h m	h m	h m	mm.	mgm.
49	Dec. 21	B—EW	4 36.2	4 38.4	4 42.2	4 44.2	4 49.0	5 0	0.3	2.0
		B—NS	4 36.7		4 43.8		4 47.0	4 55	0.4	
		W—EW		4 38.9	4 42.0		4 45.0	4 52	0.3	
		W—NS			4 44.3		4 47.0	4 50	0.4	
50	Dec. 22	B—EW			19 7.2		19 17.0	19 21	0.4	
		B—NS			19 6.6		19 16.6	19 21	0.2	
		W—EW			19 7.8		19 16.9		0.3	
		W—NS			19 7.3		19 15.9		0.1	
	1911									
51	Jan. 3	B—EW	17 38.7†	17 49.8	18 9.0	18 35.3	18 36.9	19 22	53.4	10.1
		B—NS	17 39.1	17 49.8	18 15.4	18 24.7	18 40.4	19 9	7.9	
		W—EW		17 50.2	18 9.4	18 24.0	18 35.6	19 23	9.3	
		W—NS	17 39.1	17 50.2	18 10.1	18 25.4	18 34.6	19 21	9.7	
52	Feb. 4	B—EW	22 29.9		22 36.3		22 41.9	22 51	0.8	2.3
		B—NS	22 29.9					22 53	0.4	
		W—EW	22 30.0		22 36.7		22 41.2	22 44	0.8	
		W—NS	22 30.0		22 36.8		22 40.2	22 43	0.2	
53	Feb. 18	B—EW	13 5.3		13 40.8		13 50.8	13 58	1.3	10.1
		B—NS	13 5.1		13 38.2		13 48.7	14 10	0.5	
		W—EW		13 25.0	13 36.3		13 50.0	14 7	0.4	
		W—NS			13 38.2		13 47.1	13 58	0.4	
54	April 10	B—EW	12 49.8	12 54.8	13 2.3		13 5.4	13 16	1.8	3.3
		B—NS	12 49.1	12 54.6	13 3.8		13 5.8	13 16	0.4	
		W—NS		12 54.6	13 4.0		13 5.3		0.1	
55	April 28	B—EW		4 5.7	4 8.1	4 8.3	4 10.5	4 21	0.8	2.0
		B—NS	4 0.2		4 6.9	4 7.1	4 7.8	4 12	1.0	
		W—EW				4 7.5	4 9.7		0.3	
56	May 4	B—EW	17 47.3	17 51.0	17 57.2	17 57.3	17 59.0	19 1	14.0	3.0
		B—NS	17 48.2	17 53.3	17 57.6	17 57.8	17 59.0	18 47	4.0	
57	May 9	B—EW			13 55.6		13 56.6	14 6	0.3	
		B—NS			13 55.3		13 56.2		0.2	
		W—EW			13 55.4		13 55.7		0.2	
58	May 9	B—EW			18 40.3		18 44.5	18 51	0.1	
		B—NS			18 38.7		18 42.3	18 49	0.1	
59	June 7	B—EW	5 9.0	5 14.3	5 19.9	5 25+	5 37.0	7 31	>90.0	3.6
		B—NS	5 8.8	5 14.0	5 18.8	5 26+	5 31.2	6 45	>90.0	
		W—EW	5 8.8	5 14.0	5 19.1		5 31.1	6 25	14.0	
		W—NS	5 8.9	5 13.8	5 20.1			6 2		
60	June 15	B—EW	8 40.1	8 44.5	8 50.4	9 5.0	9 26.3	10 18	4.0	3.4
		B—NS	8 39.9	8 43.2	8 53.0	8 53.2		10 13	6.0	
		W—EW		8 44.0	8 50.4	9 3.7	9 26.5	9 54	1.0	
		W—NS	8 39.0	8 44.1	8 49.5	8 53.0	9 21.1	9 47	3.4	
61	July 1	B—EW		16 16.4	16 18.8	16 19.0	16 19.2	16 34	4.5	1.5
		B—NS	16 10.5	16 14.1	16 15.9	16 16.5	16 17.5	16 45	8.0	
62	July 11	B—EW	22 30.9							
		B—NS	22 27.9	22 38.5						
63	Aug. 16	B—EW	17 1.1	17 11.0	17 34.8	17 51.1	18 9.1	18 50	1.1	10.1
		B—NS		17 12.1*	17 36.3	17 51.8	18 19.4	18 40	3.0	
		W—EW		17 11.0	17 35.1	17 51.1	18 17.1		0.6	
64	Aug. 17	B—EW	5 4.4	5 8.4	5 10.3	5 11.4	5 14.0	5 20	0.6	1.7
		B—NS	5 5.3	5 7.4	5 10.0	5 10.3	5 11.9	5 24	0.8	
		W—EW			5 8.3	5 9.6	5 11.4		0.1	

NO.	DATE	COMPONENT INSTRUMENT	P	S	L	M	K	F	A	Δ
	1911		h m	h m	h m	h m	h m	h m	mm.	mgm.
65	Sept. 12	B—EW			21 29.5		21 38		0.2	
		B—NS			21 29.0	21 30.7	21 43		0.2	
66	Sept. 16	B—EW	21 51.0	21 58.5	22 6.5	22 9.6	22 10.5	23 0	11.5	5.1
		B—NS	21 50.0		22 5.0	22 6.3	22 20.0	22 7	1.5	
		W—EW	21 49.2	21 58.1	22 6.3	22 8.0	22 10.8	22 44	1.3	
		W—NS			22 6.0		22 9.8			
67	Sept. 21	B—EW	23 10.3	23 16.7	23 24.2	23 25.1	23 26.5	23 41	2.9	4.5
		B—NS	23 10.5	23 15.8	23 23.6	23 24.2	23 26.4	23 44	2.5	
		W—EW		23 15.7	23 24.1		23 25.2	23 34	2.6	
68	Oct. 6	B—EW	4 21.6	4 26.1	4 28.6	4 33.6	4 35.6	4 46	17.0	3.0
		B—NS	4 22.0	4 26.5	4 34.5	4 37.6	4 39.7	5 10	4.0	
		W—EW	4 20.9	4 25.3	4 31.6	4 32.7	4 34.3	4 45	3.2	
		W—NS	4 20.9	4 25.3	4 32.0		4 37.6	5 0	2.0	
69	Oct. 26	B—EW			8 28.5		8 37.0			
70	Nov. 7	B—EW			0 11.8	0 12.4	0 13.3	0 22	0.9	
		B—NS			0 12.0		0 13.7	0 21	0.3	
		W—NS			0 11.7		0 13.7	0 21	0.1	
71	Nov. 18	B—EW			1 52.0	1 53.0	1 53.4	2 4	1.3	
		B—NS		1 50.4	1 51.1		1 53.6	2 4	0.5	
72	Nov. 20	B—EW		8 2.0	8 6.1		8 13.1	8 20	1.8	
		B—NS		8 1.5	8 8.5	8 9.5	8 10.7	8 17	2.0	
		W—NS			8 8.0		8 10.3	8 12	0.4	
73	Nov. 25	B—EW			1 46.7			1 51	0.6	
		B—NS			1 47.0	1 47.5	1 47.7	1 51	1.9	
		W—NS		1 46.0	1 48.0		1 49.0	1 50	0.1	
74	Dec. 16	B—EW	13 20.7*	13 26.0*	13 33.9		13 45.4	14 45	>46.0	4.2
		B—NS	13 20.6*	13 26.0*	13 32.6	13 34.2	13 38.6	14 45	35.0	
		W—EW			13 31.2		13 38.9	13 49		
		W—NS	13 20.7	13 25.8	13 31.3	13 33.9	13 38.9	14 9	12.0	
75	Dec. 20	B—EW			0 24.2		0 32.2	1 7	0.2	
		B—NS			0 23.6		0 34.6	1 0	0.1	
		W—EW			0 23.9		0 33.9	0 40	0.1	
		W—NS		0 18.1	0 23.9		0 32.9			
76	Dec. 23	B—EW	15 11.7	15 19.0	15 24.5		15 31.5	15 44	0.5	4.3
		B—NS	15 13.3	15 16.1	15 22.1		15 31.2	15 44	0.4	
		W—EW	15 16.8	15 20.3	15 22.8		15 30.8		0.1	
		W—NS	15 11.5	15 19.4	15 24.4		15 31.0	15 45	0.3	

REMARKS.

1. Motion almost entirely in E-W component. Period of vibrations 15—20 sec. at M. No record on Wiechert instruments.

2. Phases of shock are not well defined, hence P and S may be incorrect. No record on Wiechert instruments. Microseisms during the day.

3. Numerous microseisms of small intensity have preceded this shock. Faint traces of shock on W-EW. Times given for W-NS are uncertain.

4. The microseisms are numerous during the day. Times of phases of this shock are hence uncertain.

5. No preliminaries perceptible, movements of short duration.

6. P uncertain, S not perceptible.

7. A succession of long period waves of very small amplitude. Impossible to distinguish the phases. Barely perceptible on Wiechert records.

8. Microseisms during the day and preceding this shock, mask the phases. W-EW record is indistinct.

9. Record of Wiechert instrument is missing.

10. Motion consists of long slow waves of small amplitude. The phases are indistinguishable. Preceded by microseisms during the day.

11. The preliminary tremors are well marked, but it is difficult to identify them. Microseisms have preceeded this shock, and P may be obscured, P as given being in reality S. The distance is hence unreliable. The record consists of a series of pulses, lasting about 15 minutes. The pen of the E-W Strasburg pendulum moved entirely off the sheet, but this may be due to synchronism of the impulses and the period of the pendulum, as the W-EW does not indicate that the amplitude should have been sufficiently great to do this. B-N S record is incomplete as driving clock of drum stopped.

13. The phases of this shock are fairly distinct, hence the distance is reasonably accurate. B-EW record gives a series of strong waves lasting three minutes. B-N S instrument out of order. Wiechert records show long waves are of longer duration, the end of it not being clearly marked. Apparently no tremors preceded this shock.

14. This shock was a series of waves of small amplitude, period about 20 sec. M is not well defined. Distance is reasonably accurate.

15. Preliminaries are long drawn out and not distinctly marked. Duration of main waves is very short. Microseisms recorded on Wiechert records; these mask the time of P.

16. A very small disturbance, S not distinguishable. No record of shock on W-E W.

17. Principal movement in N-S component. It is uncertain which one of preliminaries is missing. Vibrations of small period and amplitude are superimposed on the long waves in N-S sheet. Not registered in W-E-W.

18. A series of waves of small amplitude, period about 25 sec. The phases are not well marked. Direction of shock probably mainly E-W.

19. The phases are not well marked. A succession of short period tremors beginning with M and continuing until 19 h 14 m, then changing with long period vibrations of small amplitude. Disturbance not registered on W-E W.

20. A small disturbance. Phases are not very distinct but the distance is probably accurate. Very slight traces of the disturbance on the W-N S record.

21. A small disturbance. The phases are not well defined.

22. A distinct shock, P not plainly marked. Distance is probably accurate.

23. Principal movement E-W. Recorded on Wiechert sheet, but times are unobtainable as signals were out of order. Distance probably accurate.

24. The record is typical of a distant shock. Not recorded on W-N S. Direction of Movement is E-W. Distance is reasonably accurate.

25. The W-N S record is not satisfactory. Evidently pendulum was not free. The long waves show short period waves superposed on them. Heavy tremors appear in E-W record 23 h 26 m to 23 h 27 m. Distance is probably accurate.

26. Probably a distant shock of small intensity. Long waves seem to be repeated at 1 h 20 m—1 h 25 m and again at 1 h 53 m—2 h 0 m. B-N S record is somewhat uncertain. Not recorded on W-N S.

27. S not distinguishable. Main shock consists of a series of separate pulses, the heaviest beginning at 1 h 0.3 m, lasting until 1 h 2.1 m. Then only small tremors until tremors of moderate amplitude begin at 1 h 26.0m; these have a period of about 25 sec. and continue until 1 h 29.3 m. Then another shock of greater amplitude from 1 h 32.6m to 1 h 34.2 m. Then a final shock beginning at 1 h 36.0 m lasting until 1 h 40.3 m, with period of 15 sec. and maximum amplitude of 6 mm. Direction of shock almost entirely E-W. Only very faint traces were observed in the W-N S.

30. A small disturbance, very faint traces in W-E W record.

31. A single shock of short duration, direction of travel probably S E-N W.

32. Very slight traces of this shock on the E-W Wiechert record.

33. Times of S are uncertain. Direction of movement mainly N-S. Time signals missing on E-W Wiechert.

34. This shock consists of a single impulse. Direction of movement nearly E-W.

35. A very feeble shock with two impulses.

Direction probably nearly N-S. Traces of this shock on the Wiechert record.

36. A very feeble shock, consists of small amplitude and short period waves, period of waves gradually lengthens.

38. Somewhat similar to microseisms, but period is longer (10 sec.). There are faint traces of this shock on the Wiechert record.

39. A single strong impulse in the B-E W record. The long waves are irregular with small amplitude (1.5 mm). The single pulse is not conspicuous on Wiechert record, hence this may be due to swing of pendulum on Strassburg apparatus.

40. Direction of movement nearly N-S. A curious movement of short period waves begins at 22 h 16.7 m (N-S), continuing for about 5 min. This begins about 3 min. later in E-W component.

41. Direction nearly N-S. Two impulses separated by about 1 min., followed by a few small amplitude vibrations, developing into the usual tail. N-S component probably stronger. Distance uncertain.

42. A very slight disturbance, not recorded on any other instrument.

43. Direction N W-S E. The preliminaries are faint. Two or more fairly distinct shocks followed by several of smaller intensity. Distance is reasonably accurate.

44. A long series of waves with period 10-15 sec. The phases are indistinguishable, the times given for them are probably incorrect.

45. Phases not clearly distinguishable, hence distance is uncertain. Major portion of record is a series of sine curves. Recorded on W-N S but time signals are uncertain.

46. Owing to continuous microseisms during the day, P and S can not be distinguished. Only very slight traces in N-S records. Times are somewhat uncertain owing to missing clock signals.

47. P and S very uncertain. Shock begins suddenly, in full force without any preliminaries in N-S components. This continues in a series of impulses.

48. A long series of tremors; phases cannot be distinguished, hence recorded times may be incorrect. W-E W times are probably the most accurate. Microseisms begin after this shock.

49. A small disturbance, phases not well defined.

50. A very slight disturbance, movement principally E-W.

51. This is the Turkestan Earthquake. The phases are quite distinct and distance is correspondingly accurate.

52. Small shock, waves of very short duration. Principally in E-W direction. Distance is uncertain.

53. Phases are not distinctly marked, hence times given may be incorrect. Shock consists mainly of slow waves of small amplitude.

54. A small disturbance. Time of L is uncertain. Only faint traces in W-E W record. Distance is uncertain.

55. A very small disturbance, consisting of a sharp impulse followed by tremors. Faint traces in W-N S record. Phases are not well marked, hence distance is uncertain.

56. A single strong impulse, followed by a long tail. Possibly a second impulse occurred 0.7 min. after the first, but this is not certain. Time signals not working perfectly, but B times are very close. Recorded on Wiechert instrument, but no times can be read.

57. A very small disturbance, no preliminaries visible.

58. A succession of waves of very small amplitude and period, not seen on Wiechert records.

59. This shock occured near the city of Mexico. Probably the heaviest shock recorded at this station. Both Strassburg pendulums swung off the sheets; hence M and maximum amplitude are unknown. Distance is somewhat uncertain. L should possibly be increased by about 2 min. Wiechert records are fair, but times are uncertain as in all severe shocks, as time signals are lost. W-N-S pen not free, hence this record is incomplete.

60. Preliminaries are fairly well marked, but the long waves are broken into groups, possibly an interference effect.

61. The California Earthquake. Preliminaries are not well marked. No trace whatever on Wiechert record; instrument apparently in good adjustment.

62. This shock begins with a group of sharp tremors (P), which last for about 1.5 min., then die out completely in the E-W component, but continuing in the N-S until 23 h, then both sheets show sinusoid curve of small amplitude. The phases are not distinguishable. No record on Wiechert instrument.

63. A long series of long period tremors. W-N S record is illegible. Phase L is not well marked.

64. P and S uncertain, a very feeble shock. The main waves consist of a single swing. Only the faintest traces on W-N S record.

65. A series of very irregular tremors of small amplitude. Not seen on Wiechert records.

66. Direction nearly E-W. Times of preliminary tremors are uncertain. W-N S record consists of a few isolated vibrations.

67. A small shock. Main waves are very irregular. W-N S record is illegible. Distance fairly accurate.

68. Earthquake occurred in Hayti. Phases cannot be clearly distinguished and determination of distance is not accurate. First portion of main waves are irregular, later portion regular and with short period (15-20 sec.).

69. A series of sinusoid curves visible only on B-E W.

70. No preliminaries visible. A small disturbance, tremors of short period.

71. Preliminaries not determined owing to continuous irregular tremors during the day. No traces of the shock on Wiechert record.

72. Phases are very uncertain owing to tremors during the day. Times of B-N S are probably the most accurate. No traces of shock in W-E W record.

73. A small disturbance. No preliminaries visible.

74. The Mexican Earthquake. A strong shock. Preliminaries are well defined. Pen on B-E W swung off sheet at 13 h 34.8 m, returning at 13 h 45.2 m. W-E W record is defective as pendulum was not free.

75.. A series of sinusoid curves, beginning and ending gradually.

76. The main waves consist of a series of sine curves. Preliminaries not well determined. Times given by B-E W and W-N S are probably the most accurate.

The equipment of this station affords a good opportunity for a comparison of the Wiechert and Bosch instruments.

The Wiechert Vertical Seismograph has so far proved generally unsatisfactory. During the period of which the observations are a record not a single disturbance was recorded. Even in the most severe (Mexican) shock of June 6, 1911, there was not the least trace of movement. Considerable time has been spent in attempting to adjust this apparatus but without much effect. Possibly the instrument is still out of adjustment, but as there is nothing in its design to indicate when it is in adjustment, our attempts have been confined to trial methods, the results of which have been only partially successful. Since the beginning of this year two very small records have been obtained. Apparently the instrument lacks sensitiveness.

Comparing the Wiechert Horizontal Siesmograph with the Strassburg Tromometers, the latter type of instrument has proven more satisfactory for the following reasons. It is decidedly more sensitive, and in practically all cases of near and distant shocks the records are more legible, and are probably more accurate. There has been very little recorded on the Wiechert instruments that has not been recorded also on the Bosch Tromometers. The reverse of this is however not true. Microseisms have been recorded many times on the Bosch instruments, of which there was not the slightest trace on the Wiechert instruments. The most serious fault of the Wiechert instruments, in addition to that already mentioned, is one of design. Namely that the earthquake record and the time signals are both made by the same recording point. If the shock is a severe one, the time signals become completely obliterated, and the times of the phases cannot always be determined. In addition the rate of the driving clock is so very irregular that the times cannot be estimated to within a quarter of a minute after an interval of five minutes.

In the beginning, the Bosch instruments were not completely adjusted, hence the periods of the

two pendulums differ considerably; the East and West being 14.5 seconds, and the North and South 9 seconds. These instruments have been used without damping, the object being to secure as large an oscillation as possible. The desirablity of this is obvious, but it is evident that it must be partially offset by the frequent loss in accuracy resulting from the impossibility of differentiating the phases of the shock owing to the continued swing of the undamped pendulum. The arrangement of damping the swing of the pendulum is certainly not an ideal one, for resulting from the design of the apparatus the damping effect increases with the amplitude of the swing, instead of remaining constant. It occurs to the writer that a more satisfactory device would be something in the nature of a small vane or disk attached to the pendulum in such a manner that the vane would move in a liquid of suitable density, the amount of damping being regulated by the size and position of the vane, or by the density of the fluid.

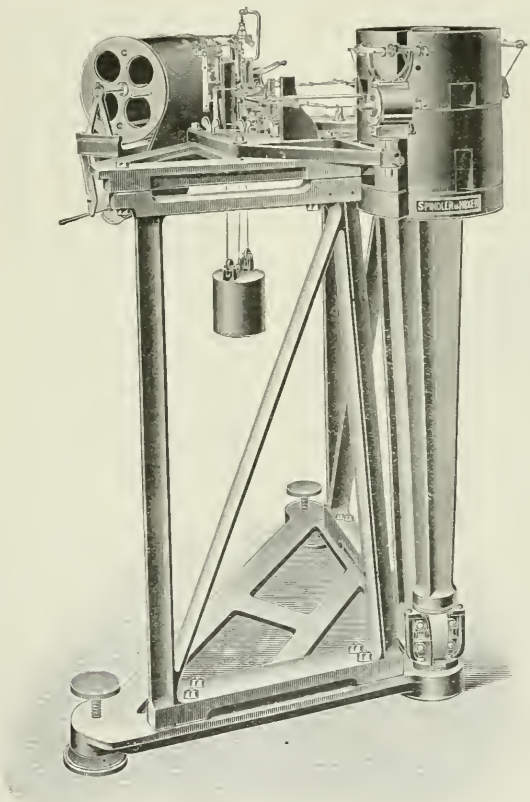

PLATE XI. THE WIECHERT HORIZONTAL SEISMOGRAPH

The period of vibration of the pendulum in the Wiechert Horizontal Seismograph is about 4 seconds. This instrument has been used with damping, the damping device seems to be satisfactory. The system of levers by which the motion of the steady mass is communicated to the recording point is rather complicated and apparently does not always perform satisfactorily. This is evidenced by the occasional absence of all traces of movement on the Wiechert record when shocks of moderate intensity have been recorded on the Bosch instruments. The two components of the Wiechert Horizontal Seismograph appear to be of unequal sensitiveness. In studying the record of microseisms it will be noted that when recorded by this instrument the record in the great majority of cases has been with the North and South component, and when recorded by both components the North and South record has been the stronger. Although this has been the rule, there have been exceptions to it, in which the East and West component was the stronger.

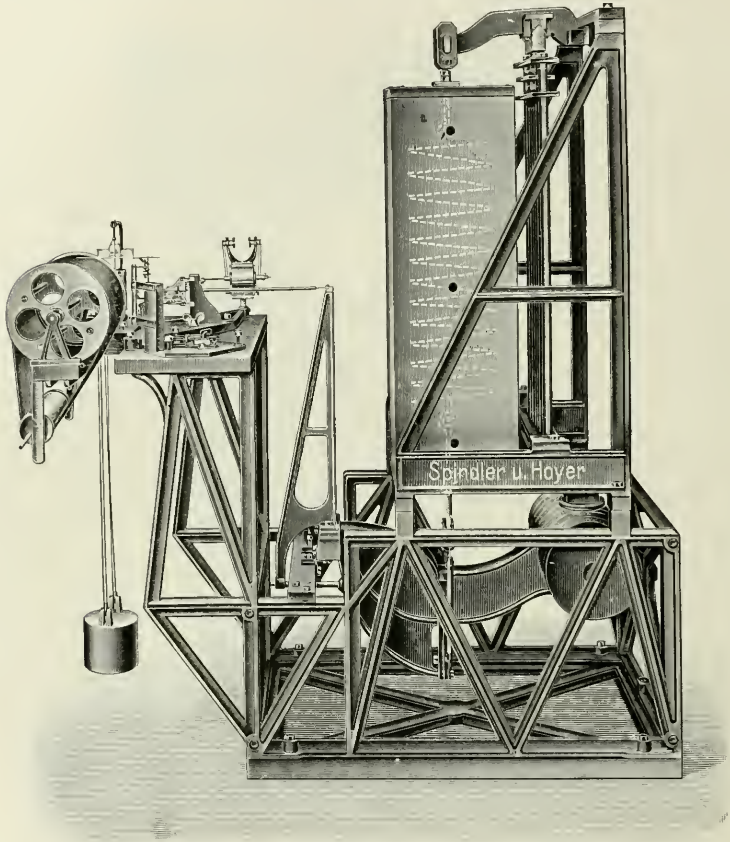

PLATE XII. WIECHERT VERTICAL SEISMOGRAPH.

The registration in all instruments is mechani-

cal, upon smoked paper. The rate of movement for the Bosch Tromometers is 15 millimeters to one minute. For the Wiechert instrument it is 10 millimeters to one minute. Other observers have noted the desirability of recording the times with an accuracy of a single second. It seems doubtful if it will be possible to do this in general. In some cases such accuracy may be occasionally reached, but in the great majority of cases the beginning of the movement is so gradual, and is frequently so completely masked by the vibrations of the pendulum, that although it might be possible mechanically to read the times with this accuracy, the result would be entirely illusory. Hence the times have been recorded to the nearest tenth-minute only.

MICROSEISMS.

In addition to the true earthquakes, and the local disturbances caused by street traffic, railway trains, etc., the seismograph records a peculiar species of very small vibrations known as "pulsatory oscillations," "microseismic unrest," or briefly "microseisms." The term microseisms will thus be understood to include all pulsatory disturbances not directly traceable to what are ordinarily known as earthquakes, and to local disturbances due to traffic, etc.

The microseisms appear on the seismogram as small amplitude vibrations of regular or irregular period, continuing without interruption for hours, and frequently for days. Many prominent seismologists have studied these disturbances with some care, but without being able to arrive at any really satisfactory explanation of the cause of the phenomenon. It has been found at this, as at other stations, that local winds, temperature changes, and pressure gradients appear to be without direct effect in producing these disturbances. It has been observed here as well as elsewhere that the microseisms are more frequently seen in the winter season than in the summer.

At this observatory the record of microseisms is somewhat embarrassed by the tremors and disturbances produced by passing railway trains. Although in general the record of passing trains is simply a thickening of the line traced by the recording point, produced by very short period vibrations of very small amplitude, lasting from 0.5 to 2 minutes, there will be frequently produced vibrations of longer period and larger amplitude closely resembling microseisms. This effect has generally been noticed when the microseisms are of small intensity, and one receives the impression that the surface of the ground is in such a condition of equlibrium that the least impulse will cause it to commence vibrating. At such times the train disturbances can easily be mistaken for microseisms.

Klotz has found that the microseisms observed at Ottawa are accompanied by the presence of a low pressure area over the Gulf of St. Lawrence and surrounded by fairly steep gradients; with increased intensity of the microseisms if there is at the same time a high pressure area on the Atlantic coast north of Florida.

Wiechert and Linke, the latter from observations made at Apia in the Pacific ocean, have concluded that in the microseisms we have to do with the oscillations set up by the pounding of the surf on the shore of the ocean. While this may be true regarding microseisms observed at Apia, it will hardly be believed that the ocean surf can have an effect in any way appreciable at Ann Arbor, which is situated more than 850 km from the nearest sea coast.

Following out Klotz' hypothesis a comparison was made between the weather maps and the dates on which microseisms had been observed at Ann Arbor. There is some evidence of correlation between the prevalence of lows over the Gulf of St. Lawrence and the microseisms at Ann Arbor. That is, during months when lows over the Gulf are numerous, microseisms will be found frequent at Ann Arbor. However there are occasions when strong microseisms were recorded here during the absence of a low over the Gulf. Similarly lows were found over the Gulf when no microseisms were recorded. The period during which observations have been made is rather short, and comparisons should be extended over a longer period before a definite conclusion can be reached.

The microseisms recorded at this observatory seem to be somewhat sharply divided into two classes. The regular or usual type with period

of vibration 7-8 seconds, and those with irregular period.

The microseisms of the regular type are the more numerous. They commence gradually, with the appearance of scattered groups of vibrations of small amplitude (Fig. 1, Plate XIII). This group arrangement of the vibrations is quite characteristic of the regular microseisms. The amplitude of the vibration increases, reaches a maximum and then diminishes, the whole lasting about a minute; the groups recurring more or less regularly at intervals of two or three minutes. The appearance seems to indicate either that it is an interference effect, or that the disturbing force acts in a series of impulses of about equal intensity but of slightly irregular period. After the maximum amplitude has been reached (usually about 0.5 mm), the microseisms may continue for a few hours or for one or more days, sometimes maintaining a constant intensity, sometimes decreasing for a while and then increasing again. The ending of the period is usually the reverse of the beginning, the tremors becoming less numerous, with smaller amplitudes until they finally cease altogether. (Fig 2, Plate XIII). So far the sudden beginning or ending of a period of microseisms has not been observed.

The grouping effect is conspicuous on the Wiechert records. The groups are more sharply defined than on the Bosch records, that is, the recording point comes to a period of absolute rest between the groups of microseisms, while the beginning and ending of each group is quite abrupt. This is doubtless a damping effect. It is rather curious that the vibrations in these groups on the Wiechert record are sometimes decidedly irregular, and at other times are quite regular. The Bosch record is however the same at both times, and nothing can be learned from it regarding the kind of "regular" microseisms that will be found on the Wiechert record.

The irregular microseisms occur less frequently than the regular. They show nothing of the group arrangement, but consist simply of continuous vibrations of irregular period and unequal amplitude (Fig. 3, and 4, plate XIII). Similar to the regular microseisms just described, they commence and end gradually. Rather strangely microseisms of this class are rarely recorded by the Wiechert instruments; even when very strong movement has been recorded on the Bosch records, there is not the least trace of this on the Wiechert record. For recording microseisms the Bosch instruments at this observatory are decidedly superior to the Wiechert.

Apparently there are two causes at work producing these two classes of tremors. On several occasions, particularly November 20-21, 29-30, 1911, the records show the irregular microseisms decreasing in intensity, while simultaneously the regular microseisms begin, with the appearance of occasional groups of tremors interspaced among the irregular vibrations. The groups gradually become more numerous, while the irregular microseisms diminish in intensity and finally disappear.

In the list given below, are noted data concerning the microseisms recorded by the seismographs at this observatory. As has been noted before, all times given are Central Standard Time, midnight to midnight. The seismograph sheets are renewed daily at about 8 hrs. (8 a. m.), hence the "seismograph day" can be considered as beginning at this time.

RECORD OF MICROSEISMS.

1909.

Sept. 8-9.

Microseisms of moderate intensity recorded on B — E W. Period of vibration about 8 sec., amplitude 0.5 mm.

Sept. 9-10.

Microseisms similar to above but less numerous. Traces of these are shown on the B — N S record.

Sept. 12-13.

Microseisms similar, but not recorded on B — N S.

Sept. 13-19.

Similar microseisms recorded during all this period on B — E W, and occasionally on B — N S. These are generally of short period and small amplitude.

Sept. 20-22.

Numerous microseisms during this period recorded in B — E W. Small amplitude.

Sept. 24-26.

Similar to above, with occasional traces of movement on B — N S.

Oct. 5-10.

Numerous microseisms during this period, very small amplitude. Traces of movement on B — N S.

Fig 1

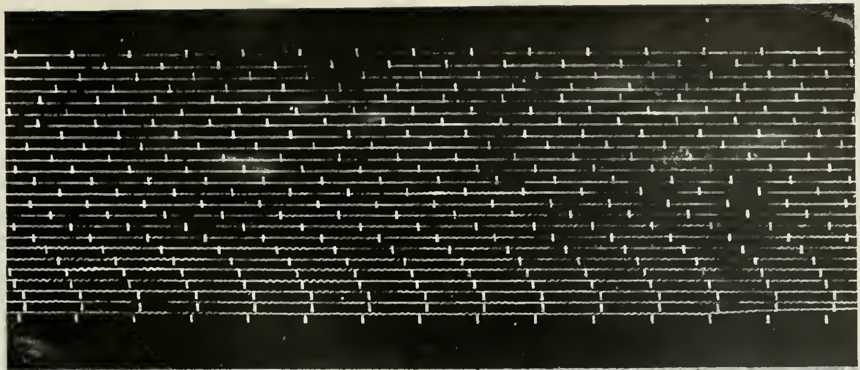

Fig. 2

Fig. 3

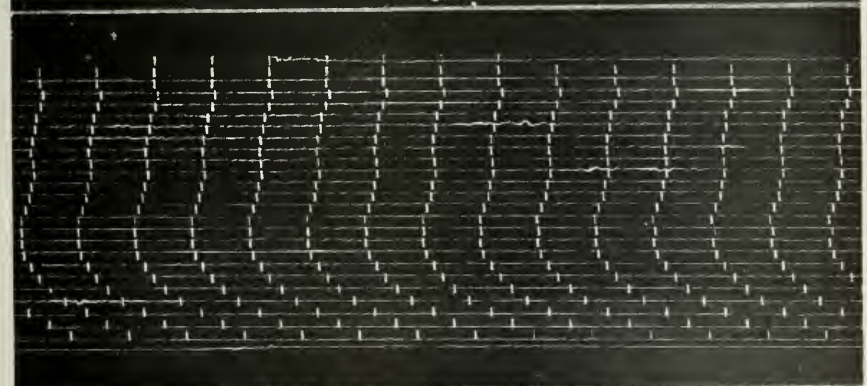

Fig. 4

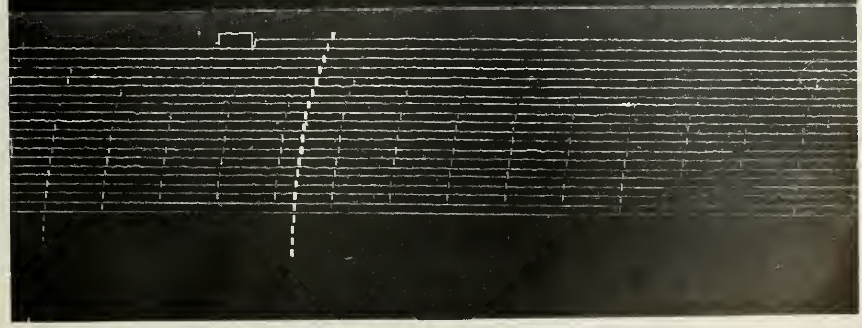

PLATE XIII.

FIG. 1. B—EW. JANUARY 20-21, 1911.

FIG. 2. B—NS. NOVEMBER 26-27, 1911.

FIG. 3. B—EW. DECEMBER 27-28, 1911.

FIG. 4. B—NS. NOVEMBER 12-13, 1911.

Oct. 12-13.
Both B — E W and B — N S records show irregular wave-like motion. This is practically continuous during the day, and of longer period than the regular microseisms. High winds.

Oct. 15-16.
Both Bosch components show numerous microseisms of small amplitude.

Oct. 22-23.
Occasional microseisms on both Bosch records.

Oct. 26-29.
Microseisms of small amplitude are almost continuous during the day. Distinct traces on W — N S record.

Nov. 6-7.
Microseisms continuous during this period. Intensity nearly equal on Bosch records, but stronger in W — N S than W — E W, small amplitude.

Nov. 10-11.
Microseisms during second half of this period. These are quite pronounced, and stronger on B—EW than B—NS. Show only very slightly on Wiechert records, in contrast to preceding period.

Nov. 11-12.
Microseisms continue, but gradually die out by the end of this period.

Nov. 24-25.
Microseisms of considerable amplitude. More conspicuous on B — E W than B — N S. Conspicuous on W — N S, with traces on W —E W.

Dec. 5-6.
Continuous tremors during the day. These are of irregular period and small amplitude, although some are as great as 0.5 mm. These tremors are particularly noticeable on the B — NS record. Only very faint traces on Wiechert records. Tremors gradually subside during A. M. of the 6th.

Dec. 7-8.
Tremors similar to above beginning about 15 hrs on the 7th, and continuing through the next day.

Dec. 8-9.
Tremors continued from the day before. These have become very prenounced. Amplitude as great as 0.5 mm, period very irregular. These vibrations in no way resemble the ordinary microseisms, being much more irregular, and continuing for hours at a time. Maximum disturbance seems to be at about 18 hrs on the 8th. Slightly more conspicuous on the B — N S record than on the E W component. Tremors seem to be absent from W — E W record, only the faintest traces on W — N S.

Dec. 9-10.
Tremors continued. Probably a small shock beginning 9 da 10 hrs 32 m continuing until 11 hrs 3 m. This is simply a series of waves of 0.5 mm amplitude, and about 15 sec. period. Not shown on B—NS, but is conspicuous on B—E W and shows distinctly on both Wiechert records.

Dec. 10-11.
Continuation of these tremors, but gradually diminishing in intensity.

Dec. 12-13.
Microseisms of the usual type, amplitude very small. Faint traces on the Wiechert records.

Dec. 17-19.
Microseisms of small amplitude recorded on both Bosch records. The period on N S record is distinctly longer than on EW; may be due to interference with the pendulum swing.

Dec. 19-20.
Microseisms of small amplitude during this period. More conspicuous on B — N S than B — E W. (This is unusual). Not visible on Wiechert records.

Dec. 26-27.
Conspicuous microseisms on both Bosch records. Slight traces on Wiechert records.

Dec. 28-31.
Strong microseisms during the beginning of this period; these gradually diminish in intensity. Visible on both Wiechert records.

1910.

Jan. 1.
Strong microseisms, very conspicuous on the B—EW record. Traces on both Wiechert records. These microseisms preceded the earthquake elsewhere recorded.

Jan. 1-3.
Very slight traces of microseisms after yesterday's shock, becoming stronger on the 3rd. These are more prominent on the B — E W and W — N S records.

Jan. 10-13.
Slight traces of microseisms on Bosch records.

Jan. 25.
Small disturbance at 16 hrs 10 min, lasting 1.8 min. This is recorded on both Wiechert sheets but not at all on Bosch records, and may be due to the presence of visitors in the seismograph room.

Jan. 27-30.
Slight traces of microseisms during this period.

Feb. 9-10.
Microseisms during this period. More conspicuous on the B — E W, and W — N S records. Faint traces have been visible for several days previous to this.

Mar. 11-12.
Microseisms of considerable intensity during this period. These are conspicuous on the W — N S record, but are absent from the W — E W. E W component is the more prominent on the Bosch records.

Apr. 3-4.
Occasional tremors of small intensity.

Apr. 15-16.
Similar to above.

May. 11-12.
Slight tremors on the Bosch records beginning 12 da 3 hrs 10 min and continuing until 3 hrs 26 min. Traces of these on Wiechert record.

Jun. 15-16.
Slight microseisms on both E W records preceding shock of this date.

Jun. 16-17.
Microseisms of small intensity frequent during this period.

July 17-18.
Occasional microseisms of small intensity during this period.

Aug. 25-27.
Similar to above. Some of these tremors may be caused by passing traffic, as the train disturbances are unusually prominent.

Sept. 18-20.
Mcroseisms of small amplitude which become more numerous towards the end of this period.

Oct. 3-4.
Traces of microseisms on all records, very small amplitude.

Oct. 11-14.
Microseisms during this period. These begin with small amplitude, growing stronger and reaching a maximum on the 13th, then diminishing. These tremors are conspicuous on both Bosch records, but only faint traces on the Wiechert records.

Oct. 14-17.
Occasional microseisms of small amplitude on Bosch records.

Oct. 18-22.
Microseisms of moderate amplitude on Bosch records, faint traces of these on the Wiechert records.

Oct. 24-25.
Strong microseisms beginning on the 25th. Conspicuous on both Bosch and W — N S records, faint traces on the W — E W record.

Oct. 25- 27.
Strong microseisms continued, intensity beginning to decrease. None recorded after the morning of the 27th.

Oct. 27-28.
Strong microseisms again, beginning on the 27th. Conspicuous on the Bosch and W — N S records.

Nov. 9-12.
Occasional microseisms during the early part of this period, becoming stronger on the 12th. Recorded with both Bosch, and W — N S.

Nov. 16-19.
Occasional microseisms during this period.

Nov. 23-24.
Occasional microseisms of moderate intensity on the Bosch records. These are very conspicuous on the W—EW record (rare), and much resemble a succession of small shocks during the day.

Nov. 24-25.
Similar to above.

Nov. 26-27.
Microseisms conspicuous on the Wiechert records. These are quite irregular and in no way similar to those usually recorded on the Bosch sheets.

Nov. 27-28.
Similar to above, but with decreasing intensity.

Nov. 28-29.
Traces of microseisms on the Bosch records. These are conspicuous on the W — E W record. Traces on W — N S.

Nov. 30-1.
Conspicuous microseisms on Weichert records, of moderate intensity on Bosch records.

Dec. 1-5.
Microseisms of moderate amplitude during this period on Bosch records. These are occasionally conspicuous on the W — E W record, and are much more irregular than on the Bosch. This may be an instrumental effect.

Dec. 7-8.
Tremors have been continuous until this date. The character now changes, the Bosch records showing irregular tremors during the day. This is especially prominent on the E W record, the tremors being very irregular and continuous. This is practically duplicated on the Wiechert sheet.

Dec. 8-10.
Similar to above, with a small shock early on the morning of the 10th.

Dec. 12-13.
Irregular tremors have continued up to this time. The character now changes, becoming more regular.

Dec. 16-17.
Microseisms beginning during the latter portion of this period.

Dec. 17-19.
Strong microseisms during the early portion of this period, these gradually disappearing during the 19th. These tremors are of the usual or "regular" type more prominent on the Bosch than on the Wiechert records. This would seem to indicate that tht Wiechert instrument is more sensitive to irregular tremors than is the Bosch, but the effect may be produced through interference on account of the periods of the pendulums.

1911.

Jan. 4-5.
Continuous irregular tremors during this period, becoming stronger during the latter portion. These are conspicuous on Bosch records but are not seen on the Wiechert sheets. This is the opposite of what has just been noted above.

Jan. 8-9.

Strong irregular tremors during the middle portion of this period. These are conspicuous on the B—EW and W—EW records with traces on the NS records.

Jan. 17-18.

Faint traces of the regular microseisms.

Jan. 20-21.

Strong irregular tremors beginning during the evening of the 20th. These are very conspicuous on the Bosch and W — E W records, traces on the W — N S record.

Jan. 21-22.

Tremors continued, but disappearing by the evening of the 21st.

Feb. 19-20.

Traces of short period regular microseisms on the Bosch records.

March 4-5.

Short period microseisms of small amplitude on Bosch records, traces of these on the Wiechert records.

April 20-22.

Short period, regular microseisms of small amplitude on Bosch records; only the faintest traces of these with Wiechert. Gradually disappearing during the 22nd.

July 3-4.

Beginning 4 da 7 hrs 46 min is a series of tremors, possibly a small shock, amplitude very small; this continues for about an hour. Recorded on both Bosch sheets but not on Wiechert.

July 24-25.

Slight irregular tremors on the B — N S record, but not recorded elsewhere.

Aug. 21-22.

Beginning at 10 hrs 54.3 min on the 21st., a series of tremors lasting about 17 min, possibly a small shock. Seen on both components of Bosch records, but absent from Wiechert.

Sept. 7-8.

Slight traces of microseisms on both Bosch records.

Sept. 8-9.

Microseisms continued, slightly stronger. Faint traces on the Wiechert records.

Oct. 2-5.

Strong microseisms, continuous and more conspicuous on the NS components of both sets of instruments than on the EW. These tremors gradually disappear during the 5th.

Oct. 13-14.

Microseisms beginning, become strong at the end of this period on all records but the W — E W.

Oct. 14-16.

Strong microseisms continued; disappearing during the 6th. Tremors are regular with small period, except from 11 hrs 10 min to 11 hrs 20 min on the 14th, during which time they are irregular and with longer period.

Oct. 23-24.

Long period tremors (15—20 sec.), with very small amplitude. The record has the appearance of a slightly wavy line. This is conspicuous on the B — N S record. Tremors not shown on Wiechert records.

Nov. 2-3.

Irregular tremors of long period and small amplitude, prominent on the B — N S record only.

Nov. 8-9.

Regular microseisms beginning during the latter part of this period. These are more prominent on B — E W than on B — N S record. Not visible on Wiechert records.

Nov. 9-10.

Microseisms continued, but disappearing toward the end of this period.

Nov. 11-12.

Strong irregular tremors beginning about 6 hrs on the 12th. These are nearly continuous, occasionally interrupted by short period vibrations. Amplitude frequently 0.5 mm. These tremors are conspicuous on both Bosch records, but only the faintest traces on the W — N S.

Nov. 12-13.

Tremors continue. B — N S record is the stronger. Not visible on Wiechert records.

Nov. 13-15.

Tremors continue, but with diminished intensity.

Nov. 17-18.

Continuous irregular tremors. These are stronger on B — E W record. Not visible on Wiechert records.

Nov. 18-19.

Very strong irregular tremors continuous during this period. These are stronger on B — E W record. Amplitude frequently over 1 mm. Wiechert record is incomplete, but there are no traces of these tremors.

Nov. 19-20.

Tremors continue, but with diminished intensity.

Nov. 20-21.

Tremors continue, but short period microseisms of the regular type are numerous and interspaced with the irregular tremors. This is of particular interest; the short period microseisms are beginning while the irregular tremors are dying out. Evidently there are two different causes at work.

Nov. 25-26.

Regular short period microseisms developing during this period and becoming very strong at the end. Very conspicuous on both Bosch records, but only faint traces on W — N S.

Nov. 26-27.

Very strong regular microseisms of short period on both Bosch records, gradually dying out on the 27th. Visible on W — E W record.

Nov. 29-30.

Irregular microseisms beginning at the end of this period, interspaced with the short period regular type. Conspicuous on both Bosch records, but no traces on the Wiechert.

Nov. 30—Dec. 1.

Irregular tremors continued, gradually disappearing.

Dec. 21-22.

A series of irregular tremors beginning 21 da 7 hrs 6 min and continuing until sheets were changed, about 24 min. This was probably a small shock, amplitude over 1 mm. On both Bosch records, but only on W — E W.

Dec. 23.

A series of irregular tremors beginning 14 hrs 1 min and continuing for two minutes, gradually dying out. This is conspicuous on W — N S but absent from W — E W. This is probably a small shock. Another follows an hour later, see elsewhere.

Dec. 24-25.

Small irregular tremors on Bosch records. Traces of these on W — N S.

Dec. 25-26.

Small irregular tremors. Not on Wiechert records.

Dec. 26-28.

Beginning 0 hrs on the 27th, strong irregular tremors commence and become stronger. More conspicuous on the B — E W record, with only faint traces on W — N S. These tremors gradually disappear by 17 hrs on the 28th.

Dec. 29-30.

Slight irregular tremors on B — E W record.

Dec. 30-31.

Continuous irregular tremors of moderate intensity on B — E W record.

Dec. 31—Jan. 1.

Very strong continuous irregular tremors. Amplitude greater than 1 mm. Very conspicuous on B — E W record, only faint traces on W — N S. These irregular tremors continue in an almost unbroken succession during the month of January. A detailed account of these will be given in a subsequent publication.

DETROIT OBSERVATORY

PUBLICATIONS

OF THE

ASTRONOMICAL OBSERVATORY

OF THE

UNIVERSITY OF MICHIGAN

VOLUME I

PAGES 73-206

ANN ARBOR:
PUBLISHED BY THE UNIVERSITY
1915

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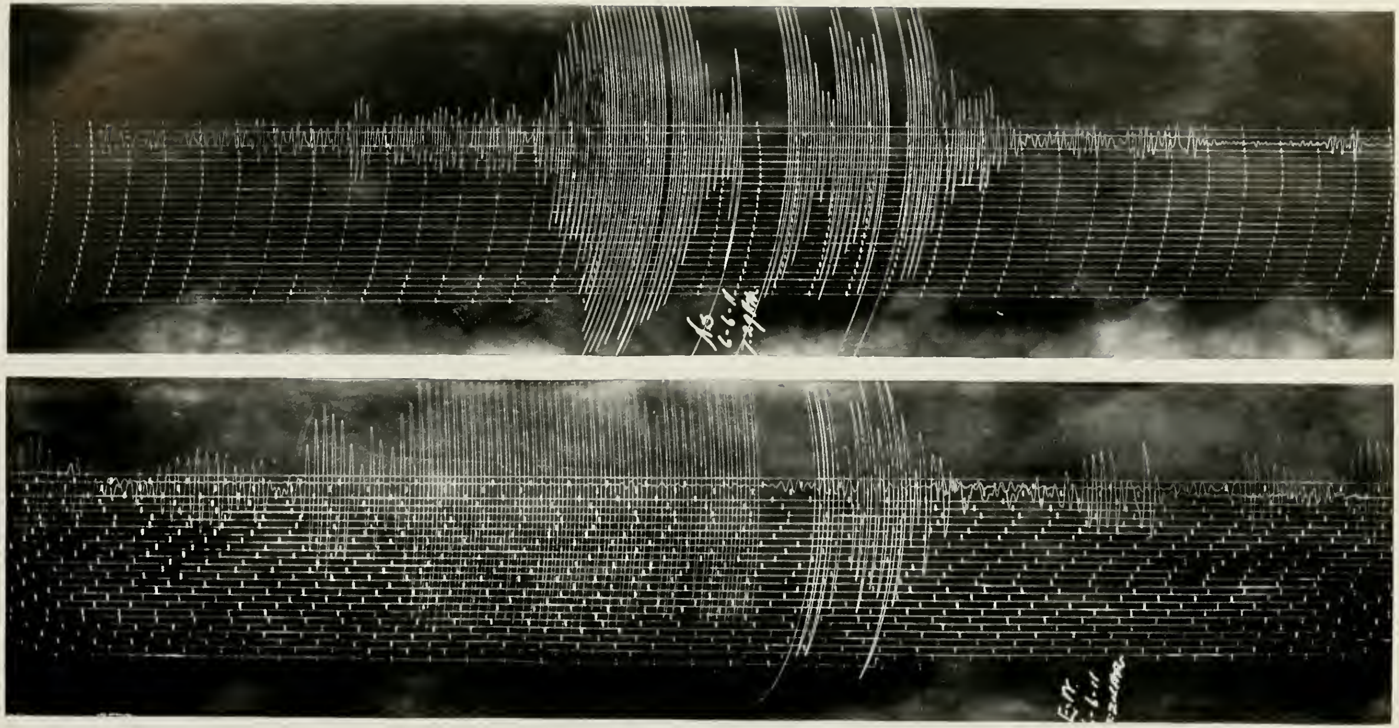

PLATE XIV. DETROIT OBSERVATORY SEISMOGRAM OF THE GREAT MEXICAN EARTHQUAKE OF JUNE 7, 1911, RECORDED BY THE BOSCH-OMORI HORIZONTAL SEISMOGRAPHS.

MISCELLANEOUS OBSERVATORY NOTES.

By W. J. HUSSEY AND R. H. CURTISS

INTRODUCTORY.

A general description of the Observatory and its equipment is given in the first part of this volume. The following paragraphs may be regarded as a continuation of that account, designed to indicate the more important additions and improvements which have been made since it was written and to give notice of the principal investigations now in progress.

THE REFLECTING TELESCOPE.

The large reflecting telescope was completed in May, 1911, and since that date it has been used on nearly all favorable nights for photographing stellar spectra. The principal series of observations, for which more than 3200 spectrograms have already been secured, are indicated below. For spectroscopic work, for which it was designed, the efficiency of the telescope has exceeded expectations. Working with an equivalent focal length of sixty feet and with a single-prism spectrograph having a dispersion of 40.3 Angstroms per millimeter at $H\gamma$, satisfactory spectrograms are obtained with exposures of six hours of stars of the 10.5 photographic magnitude, with accompanying comparison spectra. The spectra of solar type stars extend from about λ 4000 to λ 5000, and they are therefore about an inch in length. They are sharp in definition, and although usually measured under a magnification of from 12 to 15 diameters, they will if required stand somewhat higher powers up to about 20 diameters, a limit set ordinarily by the size of the silver grains in the film.

With the ability to carry spectroscopic investigations to stars of the 10.5 photographic magnitude, which is nearly two magnitudes beyond that anticipated, there is practically an unlimited amount of work available for this instrument.

The degree of efficiency which now obtains in the use of this telescope and spectroscope has been reached by a careful attention to details, and to the removal, as far as practicable, of those imperfections which existed in the apparatus when it was first installed. In the beginning the telescope and spectroscope performed excellently, but various modifications suggested by experience have been made, and through successive corrections better adjustments have been secured, rendering the instrument more easily manageable and more efficient.

NEW PRISM FOR THE SPECTROGRAPH.

The first prism which was selected for the single-prism spectrograph of this Observatory was made of Jena glass, O:102. This particular material was selected because of the stamp of approval which had been placed upon it through its prolonged use in several spectrographs, and because of the difficulties which were encountered at the Yerkes Observatory in the attempt to employ prism glass of lower density. However, when stellar spectrograms were made with our prism of this material, it was recognized at once that an excessive prismatic loss of light was taking place, especially in the important spectral region about λ 3900. Accordingly, on November 6, 1912, a new prism of Jena ordinary flint glass, similar to No. 313, was ordered from the J. A. Brashear Company, and on May 20, 1914, when our programs permitted, it was substituted for the old dispersion piece. As a result, the loss of light in our spectrograph was appreciably reduced, especially in the K region. At the same time the dispersion was reduced about five per cent. The definition and extent of field in good focus remained as before. Velocities determined with the new prism are certainly as good as those obtained with the old, while the advantage of greater transparency is an important one.

The maker's indices of refraction for the glass of the new prism are as follows: 1.6209 for λ 6563.1, 1.6259 for λ 5893.2, 1.6384 for λ 4861.5, and 1.6491 for λ 4308.0. The refracting angle of the new prism is 64° 40′; length of face, 3.18 inches; length of base, 3.40 inches; and height of prism, 1.70 inches. The deviation at the $H\gamma$

line is 59°. The dispersion for the same line is 40.3 Angstroms per millimeter, whereas for the old prism it is 37.9 Angstroms per millimeter.

A DEVICE TO COMPENSATE FOR ATMOSPHERIC DISPERSION.

Spectrographic observers who have worked with large reflectors are well aware that the image of a star at considerable zenith distances is a spectrum, only one color of which may be introduced centrally into the spectrograph slit at one time, unless it happens momentarily to lie along a vertical circle. If the guiding be done on a certain color the centers of the images of the star in other colors will in general be continually on one side or the other of the slit. Thus, only part of the light in these other colors will enter the slit, and on this account the extent of the spectrum photographed may be greatly limited. At the same time, since the star image in such other colors will be kept systematically off center with the slit, radial velocities determined from lines in regions of the spectrum corresponding to these colors may be adversely affected. Unfortunately these difficulties are especially great in the case of photographic light, which the spectroscopic observer is especially desirous of getting, and obviously the low dispersion spectrograph is more especially affected.

In order to eliminate this difficulty due to atmospheric absorption, a simple device has been tried at this Observatory by Dr. R. H. Curtiss. This device consists of a small plane parallel plate of light flint glass mounted immediately in front of the spectrograph slit in such a manner that it may be tipped at will in any direction. It is well known that a ray of white light after passage through a plane parallel glass plate at an angle emerges parallel to its original direction but with the several colors relatively displaced by amounts depending upon the angle of incidence, the optical constants of the glass, and the thickness of the plate. Conversely, if such rays of the several displaced colors be passed through such a plate at the proper angle they will be united again into a single white ray.

Similarly, the several essentially parallel beams, corresponding to the star images, relatively displaced by atmospheric dispersion, may be brought into close coincidence and thus may be united on the slit by the interposition before the slit of a plane parallel plate of suitable constants, tipped about an axis making a right angle with the vertical.

The parallelopiped used successfully to compensate for atmospheric dispersion in connection with our large reflecting telescope is of ordinary flint glass, O:103, with an index of refraction of 1.649 at λ 4300. The dimensions of the face upon which the starlight is incident are two by one and a quarter inches, and the thickness is three-fourths of an inch.

The small disturbance of the identity of source, occurring in connection with the use of this device, is not a consideration, but the light lost, chiefly by reflection at the surfaces of the plane parallel plate, amounts to about twenty per cent. Accordingly, it will require some experiment to determine the circumstances under which the advantages attending the use of this device will outweigh the disadvantage resulting from the loss of light.

IMPROVEMENTS IN THE DRIVING MECHANISM OF THE LARGE REFLECTOR.

When the 37½-inch reflector was assembled, in 1911, the various elements of the driving mechanism were set up substantially as they came from the instrument shop, without lapping, or great care in alignment and adjustment. This, of course, was done intentionally, since it was known that the accuracy of the driving under these circumstances would, for a limited time at least, be sufficient for spectrographic work.

Tests of the apparent motion of the star image on the spectrograph slit brought out many minor irregularities, a long period combination of short period terms, and, far in excess of all other periodic variations, a four-minute oscillation with a double amplitude, on the average, of about three and a half times the length of the spectrograph slit. The observation of this large oscillation, having the same period as the worm shaft, enabled us to localize the chief difficulty at once, but it was decided that all parts of the driving train should be gone over carefully and placed in the best condition possible.

Two pairs of very accurate bevel gears were

obtained from The Brown & Sharpe Company, for use between the driving clock and the worm shaft. These replaced two pairs of smaller gears which had been cut on our milling machine. The new gears, as well as the worm and worm wheel, were lapped for many hours with suitable abrasive. The shaft leading from the driving clock to the worm shaft was carefully aligned and was provided with an additional supporting bearing near its upper end. A new worm shaft was made. The four differential gears of the slow motion in hour angle were eliminated from the clock train by the simple expedient of removing the brake which forced them to revolve. The governor system was tested and made as efficient as possible. And subsequently an electric control on the governor shaft was introduced to be used for guiding of high accuracy.

These various expedients reduced greatly the minor irregularities but left the amplitude of the four minute oscillation substantially as before. Simple considerations made clear that the cause of this oscillation did not lie in the bevel gear on the worm shaft, but that it was to be found either in a periodic error in the worm or worm wheel, or in an eccentricity in the mounting of the worm. In either case it was clear that a very small *decentering* of the worm on the worm shaft would correct the difficulty with very little expenditure of time. Accordingly, the worm shaft, upon which the worm had been an accurate fit, was turned down 0.014 inches, and the bearing of the worm upon the worm shaft was restricted to two sets of opposing screws at each end of the worm. By altering these screws the worm was *decentered* a very small amount, by the method of trial and error, until the star image remained for a long period on the slit and no movement which was certainly periodic was observed. The decentering of the worm had no observable effect upon its operation aside from the accomplishment of the desired end of eliminating its periodic error. By these alterations and adjustments the driving facilities of this instrument have been made eminently satisfactory.

NEW DECLINATION SETTING CIRCLE.

When the large reflector was installed, a setting scale for hour angles was placed on the south face of the north pier, near the quick motion handles. It is within a few feet of the observer when he is making a pointing of the telescope. It has been found convenient to have an equally accessible means of setting in declination, in addition to the usual circle on the telescope. To this end a dial, three feet in diameter, made of wood and brass, has been mounted to rotate on a central pivot immediately above the declination fast motion handle. This dial, which is graduated in degrees, is in effect a large spur gear with teeth in mesh with a small spur gear on the handle shaft of the declination fast motion. To allow for back lash in the fast motion train two indices suitably placed are used for setting or reading the dial.

ELECTRIC SLOW MOTION IN DECLINATION.

An electric slow motion in declination, controlled by a switch at the eye end of the instrument, has been added to the large reflector. A motor of one-eighth horse power is used. It operates, through a differential gear, upon the large screw at the end of the slow motion sector.

A PHOTOMETRIC PLATE HOLDER FOR THE LARGE REFLECTOR.

A photometric plate holder, for use inside the Cassegrain focus of the 37½-inch Reflector, has been designed by Dr. R. H. Curtiss, and constructed in the Observatory Shop by Mr. E. J. Colliau. The plate holder is carried by a double slide, operated by racks and pinions, making possible the photography of a large number of intra-focal images, side by side. A convenient screw motion permits accurate adjustment of the distance from focus. A finding and centering telescope is also provided. An electrical shutter makes convenient the necessary accurately timed exposures. The whole apparatus is mounted, without interference, between the spectrograph and the back of the mirror cell.

A COMPARATOR FOR STAR PHOTOGRAPHS AND SPECTROGRAMS.

A large comparator, for the measurement of rectangular and polar co-ordinates, has been designed by Dr. R. H. Curtiss, and constructed in

the Observatory Shop by Messrs. H. J. and E. J. Colliau. It is similar in principle and scope to the standard Gaertner comparator, described and illustrated on page 23 of Gaertner's Catalogue A, of 1908, and there designated as A 1203. The instrument made here is considerably larger than the Gaertner model, and will measure 120 mm. in either co-ordinate. The base resembles that of the Hartman Spectrocomparator, and the microscope is supported by lateral arms. The accurate screws are each of one millimeter pitch, and may be used with heads to read microns, or with larger heads which read to half microns.

Probably the most interesting innovation in the construction of this comparator is the use of steel balls as a substitute for the main guiding ways, for carrying most of the weight of the moving parts. This relieves the horizontal screw of much of its work in moving the carriage, and reduces wear and strain. The balls, although not held apart by springs, give no trouble by massing too closely.

This comparator has been used extensively as a measuring engine for stellar spectrograms. In this connection the horizontal screw has been tested on several occasions and has been found after much use to retain its original satisfactory accuracy. For work on spectrograms a third slide is mounted on the position angle circle. This slide carries the spectrogram. It is moved by hand and is easily reversed. This instrument, though unnecessarily large for the purpose, has been found very useful and convenient for the measurement of spectrograms.

A SECOND MEASURING ENGINE FOR SPECTROGRAMS.

A close duplicate of Measuring Engine, No. 1, shown on page 52 of this volume, has been constructed by Mr. E. J. Colliau, in the Observatory Shop. The graduated head of the screw of this new engine is mounted between opposing screws, to permit decentering the head, for the elimination of possible periodic errors in the accurate screw which moves the plate carriage. However, the screw and nut which Mr. Colliau has made for this engine are so accurate that this adjustment has not been necessary.

The accurate screws of all our measuring engines are supported in a line bearing near the graduated head, and in the moving nut. The lower end of the screw of each engine is hardened and ground to a point, which bears upon a hardened and ground surface, this contact being ensured by the tension of a coiled spring, mounted at the end of the engine bed.

A HARTMANN MICROPHOTOMETER.

A Hartmann microphotometer, by Otto Toepfer and Son, for the photographic measurement of surface brightnesses, has recently been received. The instrument, as ordered, is Model 25, provided with a large round table, on which the object observed is moved about by hand under the microscope. Two Lummer-Brodhun prisms are used with the instrument, the one with a circular reflecting surface, and the other with a narrow vertical reflecting strip. An auxiliary apparatus for the preparation of photographic wedges was also obtained with the instrument.

As contemplated at the time of purchase, a triple slide plate support has been made in the Observatory Shop, to replace the round table referred to above. This was designed by Dr. R. H. Curtiss and constructed by Mr. E. J. Colliau. Two of the triple slides in this new attachment provided right and left motions for the object under the microscope, a quick hand motion, and, for accurate measures, a slow screw motion with a large graduated head. The third slide, which is operated by a rack and pinion, provides a vertical motion of the image in the microscope field. The plate carriage accommodates plates 3¼ by 4¼ inches and smaller.

The accurate screw of this triple slide plate carriage, which indeed may be used as a measuring engine if desired, is mounted in a novel manner. Near its graduated head, the screw is supported by a ball and socket joint, which has been made and lapped very carefully. The second support of the screw is the moving nut, which however serves only as a guide, since the weight of the screw balances at the ball and socket support. The lower end of the screw is free and without bearing, and the usual tension to take up back lash is supplied by a coiled clock spring. The advantage of this form of screw mounting over that in use in other engines at this Observatory is found in a reduction of the

chances of accident to the screw. This screw has been tested and has been found to possess the high order of accuracy which characterizes all the engine screws which have been made in the Observatory Shop.

PROGRAMS WITH THE LARGE REFLECTING TELESCOPE.

Work was begun with the 37½-inch Reflecting Telescope on May 19, 1911, and since that time it has been employed almost exclusively for photographing stellar spectra by means of the single prism spectrograph, described in the earlier part of this volume. More than 3200 spectrograms have been secured, distributed among the following programs:

1. *Stars of Class B, with Bright Lines.*—This program was begun on May 24, 1911, by Dr. R. H. Curtiss. To the present nearly all of the stars of this class, brighter than the fifth magnitude, have been observed, and in some cases extensive sets have been secured. The observations are being extended to fainter stars.

2. *The Early Potsdam Velocity Stars, not known to be Binaries.*—This program has been carried to completion. The observations have been made for the most part by Mr. L. L. Mellor.

3. *Long Period Variables.*—This program, now well under way, has been carried on exclusively by Dr. P. W. Merrill.

4. *Zone Stars to the Sixth Visual Magnitude, between* 35° *and* 40° *of North Declination.*—Charts and other data have been prepared for this program and a beginning has been made on the observations.

5. *Stars of Class R.*—The spectra of ten stars of Class R are being investigated by Mr. W. C. Rufus. In the course of this work several spectrograms of stars of photographic magnitude about 10.5 have been made. This program is nearing completion.

6. *Spectroscopic Binaries, Established and Suspected.*—The list of these objects, arranged in an order indicating the progress of our observations, is here given: Delta Orionis, Epsilon Orionis, 20 Tauri, the components of Zeta Ursae Majoris, Beta Cephei, Beta Lyrae, Gamma Lyrae, Gamma Cassiopeiae, Rho Leonis, R Scuti, Beta Librae, Alpha Ophiuchi, g Ursae Majoris, Alpha Cygni, 12 Canis Venaticorum, and scattering plates of other binaries. In making the plates of this program the Observatory staff has been assisted materially by Dr. G. A. Lindsay, Professor Laurence Hadley, Mr. C. C. C. Crump, and Professor G. W. Hess.

7. *Miscellaneous Objects.*—The miscellaneous objects of which spectrograms have been made include the following: Nova Geminorum No. 2, Comet Delavan, 1913 *f*, the components of Beta Cygni, several Pleiades stars, several Class N and Class O stars, the Trapezium stars, Saturn, the moon, and the sky.

THE HOWELL TELESCOPE.

The Honorable J. E. Howell, Vice Chancellor of the Court of Chancery of the State of New Jersey, a graduate of the Law Department of this University, has recently presented the Observatory a portable telescope from his private Observatory.

This telescope has a clear aperture of 4.6 inches and a focal length of about six feet. It is equatorially mounted, on a tripod, and adjustable to any latitude. The tube is of brass, highly polished, and lacquered. It is provided with a finder having an aperture of 1.3 inches, hour and declination circles, clamps, and worm gears for giving the telescope slow motions in right ascension and declination. There are six eye pieces, having powers ranging from 64 to 320 diameters.

The instrument was made by Benj. Pike's Son, New York, and has recently been put in excellent condition by Gall & Lembe. While in the possession of Judge Howell, the objective was refigured by John Byrne.

THE LAMONT REFRACTOR.

Mr. R. P. Lamont, of Chicago, has provided the funds for constructing a 24-inch refracting telescope for this Observatory. The completion of this instrument is being delayed, owing to the difficulty of producing the glass required for the objective. It was ordered in February, 1911, and although four years have now elapsed, the glass has not yet been received by the opticians. The latest report of the glass makers, at Jena, Germany, stated that the crown disk had been made, and that they had also produced a mass of flint

glass sufficiently large for the flint disk. This will have to be formed into a disk and then pass through the final annealing and testing processes, which will probably require several months. Were it not for the abnormal conditions in Europe, owing to the war, we should expect the delivery of the disks during the present year.

The mounting for this telescope is being made in the Observatory Shop and is now in an advanced stage of construction. The driving clock, clock-room section of the pier, polar head, all mechanism connected with the polar and declination axes, the lower section of the tube, draw-tube, clamps, and slow motions have been completed and assembled. The work upon the instrument has proceeded as far as is practicable until the focal length of the objective has been determined, and this must await the decision of the opticians after their examination of the glass.

THE WORK AT LA PLATA.

In carrying out its part of the agreement with the University of La Plata, the University of Michigan has, from time to time, since 1911, granted leaves of absence to Professor Hussey to enable him to organize and direct the work of the La Plata Observatory. He has now spent three periods in Argentina, aggregating five semesters, during which the principal instruments have been put in order and the following programs of observational work undertaken.

The 17-inch refractor has been used regularly for the discovery and measurement of double stars and for the observation of comets and minor planets. This work has been done principally by Professor Hussey and Mr. B. H. Dawson.

In the past much of the double star work in the southern hemisphere has been of a fragmentary character and lately there has been an insistent need of more observations. The work in this department at La Plata was undertaken with the idea of proceeding systematically, and of ultimately forming a comprehensive survey of that portion of the southern sky which is beyond the reach of northern observers. To this end Mr. Dawson confined his attention chiefly to the measurement of wide pairs which had been discovered by other observers, while Professor Hussey divided his time between searching for new pairs and the complementary measurement of those already known. This work has already resulted in the discovery of more than three hundred double stars and in securing more than three thousand observations.

The large refractor has also been used regularly for the observation of southern comets. Two hundred and one observations of ten different comets were secured in the years 1912, 1913, and 1914, and 37 observations of the minor planet (707) Interamnia. These included series of measurements of two comets discovered at La Plata, viz., Comet Westphal-Delavan, 1913, *d*, and Comet Delavan, 1913 *f*. The former was a return of Westphal's Comet of 1852, concerning whose periodic time there was so much uncertainty that it was not known in what part of the sky it would reappear. The observations secured after its rediscovery by Mr. Delavan have enabled its period to be determined with great exactness.

The second comet discovered by Mr. Delavan was new. After passing to the northern hemisphere, it was conspicuously visible to the naked eye in August, September, and October, 1914, as a circumpolar object in the latitudes of Europe and the United States. It was found ten months before perihelion passage, at a distance of nearly four hundred million miles from the sun. To be visible at such a distance its intrinsic brilliancy must have been very great, and had it not been for the circumstance that it arrived at perihelion when the earth was on the opposite side of the sun, it would scarcely have failed to be one of the great comets of history.

In the northern sky and as far south as observations can be successfully made at northern observatories, accurate positions have been found for all stars to the ninth magnitude inclusive. This condition does not obtain in the extreme southern portion of the heavens, where the positions of many stars are still inadequately known. For the solution of many astronomical problems it is desirable that the places of the southern stars should be known to the same order of completeness as in the northern sky. As a contribution in this direction observations have been inaugurated with the large meridian circle at La Plata for the determination of the places of all

stars to the ninth magnitude in the zone from 52° to 62° of south declination. This program will require about 50,000 observations, of which nearly 15,000 have already been made by Astronomers Felix Aguilar and Paul T. Delavan.

ANN ARBOR, MICHIGAN.
MARCH 20, 1915.

SILVERING MIRRORS AT LOW TEMPERATURES.

BY R. H. CURTISS.

In the directions of a large proportion of the methods for silvering mirrors, which have been proposed from time to time, we find mention or specification of temperatures above 55° F. during the period of silver deposit. In connection with the Brashear and Lundin methods, which are quite generally preferred in America at least, the recommendations with respect to temperature are fairly definite. Referring to the Brashear process we find the statement: "Operations should be performed at a temperature of 65° to 73° F. (17° to 23° C.)....If the solutions are too cold, it will be difficult to secure a coat of sufficient thickness."[1] With reference to Lundin's method it is stated that "The water for the cleaning should be lukewarm, and a trifle less for the solution."[2]

My own experience, which has been with the Brashear process almost exclusively, indicates that the precipitation of silver from the usual solutions, though relatively slow, is very complete at temperatures of 40° to 45° F.,[3] and that the production of a good mirror surface at these temperatures ought to be possible, since precipitating silver will adhere readily to a cold glass surface as actual tests, made here, show. Thus the difficulties, which have been met with in securing silver coats of sufficient thickness with cold solutions by the Brashear process, seem puzzling. However it appears probable that these difficulties may be explained simply on the basis of the fact that a lowering of the temperature of the solution causes a slower rate of precipitation of the silver. Probably in most cases of unsuccessful silvering at low temperatures, the mirror has been colder than the solution, and the chilling effect of the cold glass surface on the liquid in immediate contact with it has retarded the precipitation of silver at the very point where the formation of the free metal is required. In the meantime the silvering reaction has proceeded at a normal rate in the rest of the solution and has been completed before a coat of the desired thickness has formed on the colder mirror.

Apparently we have a difficulty here which rapid stirring will alleviate but not remove. And if much of the lack of success in silvering at low temperatures is to be accounted for in this way, it is also possible that some of the mysterious failures in silvering at the specified temperatures have been due to lack of attention to the relative temperatures of mirror and solutions during the precipitating process. At any rate the plausibility of this explanation as well as the writer's own experience suggests the formulation of this simple rule: *During the precipitating process, the mirror should not be colder than the solutions.* Ideal conditions may require a mirror temperature somewhat in excess of that of the solutions.

During the last two years there has been occasion on two winter days to silver the 37½″ mirror, in its cell. On January 27, 1914, the maximum temperature was 50° F.; the minimum for the preceding night, 35°. The day was damp and cloudy. On February 19, 1915, the outside temperature at 10 a. m. was 34° F.; at 2 p. m. in the telescope dome, 44°; and at 6 p. m. outside, 34°. On both days the temperature of the air about the mirror during silvering must have been in the neighborhood of 45° F. The rule of relative temperatures, proposed above, was carefully applied, but aside from that no attempt was made to raise the temperature of the large mirror, and the solutions (of the Brashear process) were allowed to stand in the unheated telescope room for some time before use to ensure their thorough cooling. Both of these winter coats, though forming slowly (in about twenty-five minutes), were thick, easily burnished, and brilliant. The latter of these two coats was one of the best so far secured at Ann Arbor.

ANN ARBOR, MICHIGAN.
MARCH 6, 1915.

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[1] *Popular Astronomy*, Vol. 19, p. 334. In this reference, 55° is evidently a misprint.

[2] Ibid., Vol. 19, p. 336.

[3] Lower temperatures are not mentioned because of the danger of freezing before drying of the surface is complete.

THE GEOGRAPHICAL POSITION OF THE OBSERVATORY OF THE UNIVERSITY OF MICHIGAN

By RALPH H. CURTISS

THE LONGITUDE

In a letter from Professor Francis Brünnow to the Editor of the *Astronomical Journal*,[1] dated January 27, 1858, the bare statement is made that the geographical position of Ann Ann Arbor is

Latitude, 42° 16′ 48″,
Longitude, 0h 27m 12s. West from Washington.

Five months later on June 22, 1858, in a similar letter to the *Astronomical Journal* there occurred this paragraph:

> To the kindness of G. P. Bond, Esq., I owe the communication of observations of the occultations of the Pleiades on March 19, which at last has enabled me to determine our longitude. I find for it
>
> 26m 41.0s west from Washington,
>
> which will come very near the truth.[2]

This value was soon superseded however, for a telegraphic determination of the longitude of the Detroit Observatory was effected in 1861 through a connection made with the Litchfield Observatory of Hamilton College at Clinton, New York.[3] On June 29, 126 beats of the two clocks were recorded at both stations, and on July 3, 28 comparisons were made. Before and after the exchange of signals, observations of standard stars were made by Professor C. H. F. Peters, at Clinton, and by Prof. Brünnow, at Ann Arbor. Simultaneous observations established the relative personal equation of the two observers as Peters — Brünnow = + 0.04s ± 0.008s. This value in combination with the observed difference of local time at the two stations yielded the following value of the longitude difference between the two observatories.

Detroit Observatory (Meridian Circle)
—Litchfield Observatory (Transit)
= + 33m 17.73s ± 0.027s.

On August 16 and October 3, 1859, the longitude west of Cambridge of the Litchfield Observatory had been determined telegraphically by Observers, C. H. F. Peters at Clinton, and G. P. Bond, at Cambridge.[4]

After correction for personal equation the longitude difference between these two stations was found to be

Litchfield Observatory (Transit)
—Harvard College Observatory (Center of Dome)
= + 17m 6.48s ± 0.039s.

Thus the longitude difference between Ann Arbor and Cambridge was determined as

Detroit Observatory (Meridian Circle)
—Harvard College Observatory (Center of Dome)
= + 50m 24.21s ± 0.047s.

The Detroit Observatory was again connected telegraphically for longitude purposes, with Cambridge, Mass., on three nights in 1869 with Observers A. T. Mosman and F. Blake at Cambridge and Professor J. C. Watson at Ann Arbor.[5] But the record leads to the inference that no determination of the relative personal equation of the observers involved was ever made. And the results of this longitude campaign do not seem to be available. The old observations, of 1861, still furnish the accepted data upon which is based the published values of the longitude of the Detroit Observatory.

The value of the longitude difference, Detroit Observatory — Harvard College Observatory (+ 50m 24.21s ± 0.047s), combined with the published value of the longitude of the Harvard College Observatory (4h 44m 30.98s ± 0.04s west of Greenwich) as determined by the cable observations of 1866, 1870 and 1872, yielded the value, 5h 34m 55.19s ± 0.06s west of Greenwich, for the longitude of the Detroit Observatory Meridian Circle. This value of the longitude was introduced into the American Ephemeris for 1896 and has not been altered since.

[1] *Astronomical Journal*, Vol. 5, p. 112.
[2] *Astronomical Journal*, Vol. 5, p. 145.
[3] *Astronomical Notices*, No. 27, p. 17.
[4] *Astronomical Notices*, No. 15, p. 113.
[5] *United States Coast Survey Report*, 1869, p. 15.

In 1892 longitude signals were again cabled across the Atlantic, this time between Greenwich and McGill University Observatory, Montreal, Canada; and the Montreal station was connected telegraphically with the Cambridge and Albany stations of the Longitude Net of the United Coast and Geodetic Survey. The final value[6] of the longitude west from Greenwich, of the Dome of the Harvard College Observatory at Cambridge as adjusted in June, 1897, was 4h 44m 31.046s ± 0.048s. Adding to this the above value of the longitude of Ann Arbor west of Cambridge we obtain the following improved value of the longitude west from Greenwich of the Meridian Circle of the Detroit Observatory,

5h 34m 55.256s ± 0.065s.

On three occasions longitude signals were exchanged between the Detroit Observatory and a former station of the United States Lake Survey in Detroit. Two of the resulting determinations are available. In 1861,[7] the difference of longitude of Ann Arbor and Detroit was determined by six nights exchange of signals as 2m 43.30s ± 0.046, the observers at Detroit being Lieutenant O. M. Poe and Assistant James Carr and at Ann Arbor, Professor Brünnow. In 1864[8] this difference was again determined by three nights exchange of signals as 2m 43.17s, the observers at Detroit being Col. W. F. Reynolds and Assistant S. W. Robinson and at Ann Arbor, Professor Watson. Personal equation was applied in both cases. In the second exchange of longitude signals between Ann Arbor and Detroit apparently there was no telegraph line running to the Detroit Observatory. The signals from Ann Arbor seem to have been sent from a chronometer which was carried to the telegraph office. But in discussing these determinations on page 716 of *Professional Papers, Corps of Engineers, U. S. A., No. 24*, the two determinations were given equal weight. Taking the mean then of these two results, we have 2m 43.23s. Applying the correction (—0.127s) to reduce the old transit post to the east transit post of the Lake Survey Observatory of 1871 there results

Detroit Observatory (Meridian Circle)
—East Transit Post, Lake Survey Obs. of 1871, Detroit
= + 2m 43.10s ± 0.05s,

in which the probable error is estimated from the agreement of the two sets and is indicated by the given probable error of the 1861 determination.

Through direct measurement from the neighboring longitude station of 1891, which belongs to the longitude net of the United States Coast and Geodetic Survey, the longitude of the east transit post of the Detroit Lake Survey Station of 1871 has been found to be

5h 32m 12.196s ± 0.050s[9]

which in combination with the above longitude difference between Ann Arbor and Detroit furnishes a second value for the longitude of the Meridian Circle of the Detroit Observatory west of Greenwich,

5h 34m 55.296s ± 0.07s.

Thus there are now available two determinations of the longitude of the Detroit Observatory, made some fifty years ago through telegraphic connection with stations of the longitude net of the United States Coast and Geodetic Survey. Combining these two consistent determinations and rounding off to the nearest hundredth of a second we obtain for this constant,

Longitude of the Detroit Observatory Meridian Circle West of Greenwich,
5h 34m 55.27s ± 0.06s,

in which the dependence of the result upon the same trans-Atlantic connections is taken into account in deriving the probable error.

THE LATITUDE

The provisional value of 42° 16′ 48″ for the latitude of the Detroit Observatory as reported by Professor Brünnow in 1858, was adopted by the American Ephemeris and with the addition of a zero in the tenths place of seconds is still in use in that publication. In the meantime two accurate and independent determinations of the latitude of this Observatory have become available.

[6] *U. S. Coast and Geodetic Survey Report*, 1897, App. 2.
[7] *U. S. Lake Survey Report*, 1861.
[8] *U. S. Lake Survey Report*, 1865.
[9] *U. S. Coast Survey Report*, 1897, p. 261.

which establish a far more reliable value of that quantity.

The first of these latitude determinations was made by Dr. Ludovic Estes with the Three-Inch Transit Instrument used as a Zenith Telescope.[10] From observations upon 138 pairs of stars by Talcott's method, made between October 6, 1886, and February 9, 1887, the latitude of the Observatory was determined with the result,

$$\phi = 42^\circ\ 16'\ 48''.66 \pm 0''.051$$

referred to the Meridian Circle.

The second determination of the latitude of this observatory came as a by-product of the meridian circle observations of Professor Harriet W. Bigelow, made in the years, 1901, 1902 and 1903, for the determination of circumpolar star positions.[11] From direct and reflected observations of twenty-six stars there resulted a very consistent set of values of the latitude of the Detroit Observatory Meridian Circle, ranging from 48.″42 to 49.″35, with a mean value,

$$\phi = 42^\circ\ 16'\ 48''.76 \pm 0''.06.$$

Combining these two values of the latitude with weights depending on their probable errors we obtain the value,

$$\text{Latitude} = 42^\circ\ 16'\ 48''.70 \pm 0''.04,$$

referred to the Meridian Circle of the Detroit Observatory of the University of Michigan.

A determination of the latitude of this observatory in agreement with the above value was made by Professor A. Hall from meridian circle observations of circumpolar stars in the years, 1898-1901.

THE ELEVATION.

The elevation of the Detroit Observatory, in use for many years, probably derived from railway levels, has been taken as 936 feet or 285 meters, this being the assumed height of the cistern of the barometer. The axis of the Meridian Circle is 3.02 feet higher.

More reliable values of the altitude of the Detroit Observatory above sea level are now available, based upon a bench mark with a marked elevation of 881.861 feet, which has been placed in the south wall of the University Library by the United States Geological Survey. Results of a series of levels between this bench mark and the Observatory, run by students during the spring of 1912 have been kindly furnished by Professor H. H. Atwell of the Department of Engineering of the University of Michigan. These may well be recorded here for reference. They furnish values of the elevation of the concrete floor at the base of the first column inside the south west entrance of the 37½-Inch Reflector Dome of the Observatory, above the Library Bench Mark.

Elevations of Basement Floor, Observatory Dome, Above Library Bench Mark.

Party No. 1	26.24 feet	
	26.14	
Party No. 2	26.20	
		27.45 rejected [1 foot (?) in error]
Party No. 3	26.15	
	26.41	
Party No. 4	26.39	
	26.15	
Party No. 5	26.05	
Mean	26.216 feet ± 0.032 feet.	

Thus we have the following result:
Elevation of Observatory Basement Floor 908.08 feet.

Levels run inside the Observatory by the writer measure the elevation of the axis of the Meridian Circle and of the cistern of the standard barometer above the basement floor of the 37½″ Reflector Dome as 18.24 feet and 15.22 feet respectively. Thus we have, referred to sea level:

The elevation of the axis, meridian circle..........926.32 ft or 282.35 meters,
The elevation of the barometer cistern ....923.30 ft or 281.42 meters.

Collecting for convenience of reference the above values of the terrestrial co-ordinates of the cube of the Meridian Circle of the Detroit Observatory we have the quantities below.

CO-ORDINATES OF THE DETROIT OBSERVATORY.

LONGITUDE, 5h 34m 55.27s ± 0.06s, West of Greenwich.

LATITUDE, 42° 16′ 48.″70 ±0″.04 North.

ELEVATION, 926.32 feet, or 282.35 meters above sea level.

The writer wishes to acknowledge the kindness of Professors Asaph Hall and Harriet W. Bigelow in verifying some of the data in this paper.

January, 1913.

[10] *Detroit Observatory Publications*, Vol. I, p. 28.

[11] *Astronomical Journal*, Vol. 24, p. 102. Also *Proceedings of the Washington Acad. of Science*, Vol. 7, pp. 189-194, 1905.

A DETERMINATION OF THE VISUAL LIGHT CURVE OF BETA LYRAE

By RALPH H. CURTISS

Introduction.

Although the discovery of the light variation of β Lyrae dates back nearly one hundred and thirty years, the determination of the conditions in the system of this star continues to be to a considerable extent, an unsolved problem. That this problem is rated as a difficult one is due in some degree to the lack of success which has attended the efforts of those who have addressed themselves to its solution with the aid of inadequate instrumental equipment. But in the main the difficulties attending the study of this problem are real ones resulting from the unusual and complicated changes which are established and suspected both in the dispersed and total light of this star. At the same time the importance of this problem is widely recognized since β Lyrae is the brightest known representative of a class of variable stars whose members are thought to illustrate the earlier stages in one type of double star evolution.

In view of the importance of the "Problem of β Lyrae" it is fortunate that we have available some 450 photometric determinations of the magnitude of this star made in four different years at the Harvard College Observatory. One set of these observations is used later on in this paper. But, in view of the relatively small number of these photometric measures, for the present and possibly for some time to come, we must depend largely on naked eye comparisons for our knowledge of the minor features and changes in the visual light curve of this star. It is therefore unfortunate that the limitations of visual methods should be so great; and at the same time it would seem of considerable importance that the psychological and other sources of uncertainty which affect visual comparisons be investigated and kept in mind.

ERRORS IN LIGHT ESTIMATES.

Argelander, whose visual comparisons of naked eye stars have set a standard of accuracy for the last seventy years, was fully alive to the importance of the sources of error which affect observations of this kind. He recognized the effect of variations of the Purkinje phenomenon in causing discrepancies between the results of different observers. He assigned due importance also to the remarkable persistent differences between estimates of different observers of the relative brightness of any two stars of the *same* color. Possibly he intended that these explanations should be extended to account for some of the variations in the results of the same observer in different years, such as his suspected variation in the brightness of δ Lyrae. Certainly these considerations must be kept in mind.

In connection with the Purkinje phenomenon it may also be considered that the apparent relative brightness of any two stars of different colors depends to some extent upon the brightness of the background of sky light.

Further, as the result of personal differences in color perception, the application of visual methods to the study of the light variations of certain short period variables may be expected to be followed by discrepancies among the results obtained by different observers, and probably among those obtained by the same observer in different years. It is well known that the variations of certain short period variables are different in different colors. We should therefore expect to find persistent differences in these cases between the results of an observer whose eyes are most sensitive to green or greenish yellow light and those of another observer whose eyes are most sensitive to yellow or yellowish red light. Very probably this effect will account for some observed discrepancies among the results of different observers as well as unexplained variations in the results of the same observer in different years.

Aside from errors due to differences in color perception there are psychological or optical difficulties which have important bearing on the pres-

ent problem. Of these we may consider first the effect on the apparent relative brightness of two stars due to changes in their relative position in the sky. Several observers have noted that of two stars of equal brightness the lower appears to them the brighter. Whether this effect depends only on the difference of altitude of the stars compared, or whether it depends on the direction of the line joining them is perhaps unknown, but probably both factors are involved. Judging from my own experience this effect is one which varies considerably in magnitude at different times, depending perhaps on the condition of the eyes as regards fatigue. The actual extent of this "hour angle effect" in my own case is considered later on in this paper.

Another recognized source of error, which may affect strongly any given series of light comparisons, is that which results from the tendency of the observer to estimate as equal, the brightness of the variable and of any comparison star from which it differs slightly. It is readily seen that this tendency may introduce minor irregularities in the form of a light curve such as those that appear often in published results.

Probably the source of error that may have the greatest effect upon any single observation is that due to mental preoccupation or bias. And the final curve may be greatly affected if the results are watched too closely, or follow at intervals so short that the mental processes attending one observation are still fresh when a second is made.

In addition, the visual estimates must share with photometric observations the uncertainties which arise from atmospheric absorption.

METHOD OF OBSERVATION.

In view of the above considerations it would seem that certain methods of attack, requiring more or less co-operation might facilitate the determination of the character and changes of the light curve of β Lyrae. For the determination of the mean brightness of this star, as well as the magnitude range, we must of course depend largely upon the results for the comparison stars obtained with the photometer. But in the determination of the form of the curve and of variations in the magnitude range, naked eye comparisons have yielded most valuable results and very probably could be made even more productive if observations were properly organized. But the feasibility of any extensive scheme of co-operation is very doubtful, and for the present it remains for each observer to follow the method of attack which in his judgment will contribute best to the solution of the problem. For the present series of observations, as described below, the writer has adopted, after some experiment, a simple system of light comparison which may be characterized as a special application of Argelander's method.

Two comparison stars only were chosen, both very near the variable. The brighter of these two stars was very nearly equal in magnitude to the variable at maximum light, while the fainter comparison star was a little fainter than β Lyrae at minimum brightness. The difference in brightness between the two comparison stars was about one and two-tenths magnitudes and in the comparisons, one-tenth of this magnitude difference was taken as the unit of measurement, and in terms of this unit the difference of brightness of the variable and the two comparison stars was estimated directly. The estimates thus made were converted into magnitude differences by the application of the proper factor, and, finally, magnitudes of the variable were obtained from the comparison star magnitudes by direct addition or subtraction of these determined differences.

In selecting this method of observation it was kept in mind that the results might not contribute definitely to our knowledge of the general form of the light curve of β Lyrae, because of the difficulty in extending the unit of measurement over the relatively large light intervals involved. But it was hoped that information might be gained with reference to phase times, minor irregularities and certain sources of error, more particularly, by a method differing somewhat from that ordinarily employed; and the nearness of the comparison stars to the variable was held to be an important consideration.

THE COMPARISON STARS.

The stars used in comparisons with β Lyrae were γ and δ of the same constellation. The

former is about two degrees and the latter about three and one-half degrees from the variable.

So far as I know, γ Lyrae has never been suspected of variability. Although different observers seem to receive distinctly different impressions of its brightness, its light seems constant in the results of any given observer and the variations noted seem to be assignable to subjective difficulties. A velocity variation of about twenty-five kilometers with a period of about twenty-five days was announced for this star by Professor S. A. Mitchell in 1909. Radial velocity observations made at this observatory indicate that the velocity range for this star is much less and the period, if it exists, much greater, than the corresponding announced values. The magnitude assigned to this star, taken from the *Revised Harvard Photometry*, is 3.30.

δ Lyrae is a visual double star the components of which have magnitudes, 4.52 and 5.51, the spectral types being Mo and B3 respectively. As the fainter star is distant about twelve minutes of arc from the primary, its light is not added to that of the primary when observed with the naked eye. At least the best assumption seems to be that such is the case. The radial velocity of the fainter star is variable in an unknown period. The radial velocity of the brighter star is constant so far as known. Argelander suspected this star of light variability though the differences between his determinations of its brightness, at different epochs, referred to neighboring stars, did not exceed 0.06 magnitudes. Subsequently other observers have used δ Lyrae as a comparison star apparently without suspicion, and from my own observations there seems to be no certainty of its variability, though recent results of Stempel and Lau suggest a light change of some character. To the present it has not found a place in catalogs of variable stars.

THE OBSERVATIONS.

Employing the above method and comparison stars, observations of the brightness of β Lyrae were begun by the writer in 1907 in connection with spectrographic observations, the results of which have already been published. The magnitude observations have been continued and the results of the first six years (1907-1913), comprising 612 observations, are discussed in this paper.

Table I contains the essentials of the Journal of Observations. Column 1 contains the observation number; column 2, the civil date in Greenwich Mean Time. The third column gives the phase time for each observation referred to the last preceding principal minimum computed on the basis of Pannekoek's revised formula,

$$T \text{ (Prin. min.)} = 1855 \text{ Jan. } 6^d.604 \text{ G. M. T.} + 12^d.908009\, E + 3^d.855\, t^2 - 0.047\, t^3,$$

where E represents the number of complete periods since the initial epoch and $t = E/1000$. In the fourth column the comparison of the variable with γ Lyrae is given according to the method described above. The unit or step is the tenth of the difference in magnitude of γ Lyrae and δ Lyrae. Observations with positive or negative signs indicate that the variable was fainter or brighter respectively than the star, γ Lyrae. In this column, there occur seven comparisons of the variable with stars other than γ and δ Lyrae. These are not reduced in this paper.

In column 5, the hour angle of the approximate region of the stars observed is given for each observation and in column 6, brief notes are copied from the observing journal. The numbers in this column refer to the phase of the moon, "4" denoting a full moon.

TABLE I. OBSERVATIONS OF β LYRAE.

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
1	June	8.73	7.14	+2.00	—1.5	
2		9.65	8.06	+1.50	—3.4	
3		11.68	10.09	—0 50	—2.6	
4		11.71	10.12	+0.00	—1.9	
5		14.73	0.22	6.50	—1.4	
6		15 61	1.10	5.00	—3.8	
7		15.61	1.10	$o1\beta3\delta$	—3.8	
8		15.61	1.10	$\beta=\theta$	—3.8	
9		16.67	2.16	2.00	—2.3	
10		17.60	3.09	0.50	—4.2	
11		17.65	3.14	0.40	—3.0	
12		17.65	3.14	$\gamma0.5\beta4.5o$		
13		18.65	4.14	$\gamma1\beta4\theta$	—2.9	
14		18.65	4.14	0.40		
15		20.63	6.12	3.50	—3.2	
16		20.63	6.12	$\gamma2\beta3o$	—3.1	

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
17		24.63	10.12	0.00	—2.8	
18		25.65	11.14	0.83	—2.4	
19		26.68	12.17	5.00	—1.4	
20		26.68	12.17	$\theta 1 \beta 10$	—1.4	
21		27.67	0.25	6.75	—1.8	
22		30.68	3.26	0.00	—1.2	
23		30.82	3.40	0.00	+2.0	
24	July	3.58	6.16	3.50	—3.4	
25		3.70	6.28	3.50	—0.7	
26		3.70	6.28	$\beta=\frac{o+\xi+\theta}{3}$	—0.7	
27		4.67	7.25	3.00	—1.3	Thick smoke Poor ? δ just visible
28		5.58	8.16	1.50	—3.2	Smoky
29		6.71	9.29	0.50	—0.2	
30		7.61	10.19	0.00	—2.4	
31		7.73	10.31	0.50	+0.3	
32		12.67	2.33	+0.33	—0.8	
33		12.77	2.43	—0.33	+1.7	
34		13.69	3.35	+0.15	—0.8	
35		14.71	4.37	2.00	—0.4	
36		14.74	4.40	1.00	+0.3	
37		17.71	7.37	3.50	+0.6	
38		18.60	8.26	1.25	—1.7	
39		18.81	8.47	0.50	+3.0	
40		20.63	10.29	0.25	—1.2	
41		20.71	10.37	1.00	+0.8	
42		20.83	10.49	0.00	+3.8	
43		23.65	0.39	7.25	—0.5	Bright moon
44		23.75	0.49	7.00	+2.0	Bright moon
45		24.65	1.39	3.00	—0.5	Moon
46		26.62	3.36	-0.00	—0.8	Moon
47		26.78	3.52	0.33	+2.2	Moon
48		27.71	4.45	0.25	+1.2	Moon
49		29.71	6.45	3.00	+1.4	
50		30.58	7.32	2.50	—1.6	
51		30.73	7.47	2.00	+1.9	
52	Aug.	1.58	9.32	0.33	—1.5	
53		1.71	9.45	0.50	+1.5	
54		1.79	9.53	0.50	+3.5	
55		2.71	10.45	1.00	+1.6	
56		3.82	11.56	2.25	+4.4	
57		4.60	12.34	5.50	—0.7	
58		6.65	1.47	4.25	+0.4	
59		6.73	1.55	2.00	+2.4	
60		7.58	2.40	0.25	—1.1	
61		7.65	2.47	0.25	+0.6	
62		7.75	2.57	0.00	+2.9	
63		9.65	4.47	0.00	+0.6	
64		9.80	4.62	1.00	+4.4	
65		10.62	5.44	2.25	+0.2	
66		11.62	6.44	3.75	+0.2	
67		11.67	6.49	4.00	+1.2	
68		11.81	6.63	3.33	+4.7	
69		12.62	7.44	2.25	+0.3	

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
70		13.65	8.47	0.50	+0.8	
71		13.73	8.55	0.00	+2.8	
72		14.65	9.47	0.25	+0.9	
73		15.60	10.42	0.50	±0.0	
74		15.75	10.57	0.75	+2.5	
75		17.65	12.47	6.25	+1.1	
76		18.73	0.63	5.75	+3.0	
77		19.54	1.44	3.00	—1.3	
78		19.65	1.55	2.00	+1.2	
79		19.71	1.61	1.25	+2.7	
80		19.74	1.64	0.75	+3.4	
81		22.56	4.46	0.25	—0.6	
82		24.67	6.57	3.00	+2.1	
83		25.56	7.46	4.00	—0.4	
84		25.73	7.63	2.25	+3.6	
85		25.75	7.65	2.25	+4.1	
86		26.56	8.46	0.25	—0.3	
87		28.73	10.63	0.50	+3.8	
88		30.67	12.57	7.25	+2.5	Faint
89		31.60	0.58	7.75	+1.0	
90		31.71	0.69	7.50	+3.5	
91	Sept.	1.69	1.67	5.00	+3.1	Smoky
92		5.60	5.58	1.00	+1.4	
93		6.54	6.52	1.75	—0.1	
94		6.71	6.69	2.50	+3.9	
95		12.63	12.60	7.75	+2.0	
96		18.54	5.60	0.75	+0.4	Full moon
97		19.59	6.65	5.00	+1.7	Full moon
98		19.67	6.73	4.00	+3.5	Full moon
99		20.59	7.65	1.50	+1.8	
100		22.54	9.60	+0.00	+0.7	
101		22.62	9.68	—1.00	+2.7	
102		24.54	11.60	+0.00	+0.8	
103		24.65	11.71	+0.75	+3.3	
104		30.54	4.68	0.00	+1.2	
105		30.67	4.81	0.50	+4.2	
106	Oct.	1.69	5.83	2.50	+4.5	
107		2.67	6.81	2.50	+4.3	
108		4.67	8.81	+0.75	+4.5	
109		5.54	9.68	—0.50	+1.5	
110		5.67	9.81	—0.25	+4.5	
111		6.67	10.81	+0.25	+4.6	
112		8.67	12.81	10.00?	+4.7	Eyes tired
113		9.62	0.84	8.00	+3.8	
114		9.69	0.91	7.25	+5.3	
115		14.58	5.80	1.75	+3.1	Moon
116		14.67	5.89	2.25	+5.1	Moon
117		16.58	7.80	1.00	+3.2	Moon
118		17.62	8.84	0.25	+4.3	Full moon
119		18.54	9.76	0.25	+2.4	Full moon
120		18.67	9.89	0.00	+5.4	Full moon
121		20.68	11.90	3.33	+5.8	Moon
122		21.67	12.89	9.00	+5.6	Moon
123		23.6±	1.90	1.00	+3.7	
124		25.48	3.78	+0.00	+1.3	
125		25.58	3.88	—0.50	+3.8	

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
126		29.52	7.82	+1.00	+2.6	
127	Nov.	7.46	3.84	—0.25	+1.7	
128		8.56	4.94	+0.25	+4.2	
129		12.60	8.98	0.75	+5.5	
130		22.50	5.96	1.50	+2.7	
131		23.52	6.98	2.75	+3.2	
132	Nov.	26.48	9.94	0.50	+3.4	
	1908					
133	Jan.	5.48	11.19	0.33	+6.0	
134	April	16 73	10.08	0.00	—5.2	
135		21.69	2.12	0.75	—5.9	
136		25.71	6.14	4.00	—5.1	
137		29.71	10.14	0.25	—4.9	
138	May	2.75	0.26	7.50	—3.7	
139		9.71	7.22	1.50	—4.2	2
140		11.75	9.26	0.50	—3.1	—
141		15.71	0.30	7.00	—3.0	—
142		21.62	6.21	4.00	—5.4	0
143		21.73	6.32	4.25	—2.9	0
144		22.69	7.28	2.00	—3.8	0
145		22.71	7.30	1.75	—3.3	0
146		23.62	8.21	+1.00	—5.4	0
147		23.83	8.42	—0.50	—0.4	0
148		24.62	9.21	+0.75	—5.2	0
149		26.67	11.26	0.75	—4.1	0
150		26.75	11.34	1.50	—2.1	0
151		27.73	12.32	6.00	—2.5	0
152		28.69	13.28(0.36)	8.00	—3.5	0
153		30.67	2.34	0.00	—3.8	0
154	June	1.71	4.38	0.50	—2.7	0
155		2.69	5.36	1.75	—3.1	0
156		3.71	6.38	3.50	—2.6	0
157		4.69	7.36	2.00	—3.0	—
158		6.65	9.32	0.50	—4.3	—
159		11.62	1.37	5.00	—4.0	3
160		11.71	1.46	5.00	—2.0	3
161		19.67	9 42	0.50	—2.5	0
162		20.71	10.46	0.00	—1.5	0
163		21.67	11.42	0.50	—2.4	0
164		22.75	12.50	7.50	—0.3	Sky thick 0
165		23.62	13.37(0.46)	8.50	—3.3	
166		24.62	1.46	4.00	—3.2	
167		25.67	2.51	0.75	—2.1	
168		26.62	3.46	0.50	—3.1	
169		27.67	4.51	0.00	—2.0	—
170		28.77	5.61	2.00	+0.6	—
171	July	4.71	11.55	2.00	—0.5	—
172		5.65	12.49	6.25	—2.0	1
173		7.67	1.59	2.50	—1.3	2
174		10.65	4.57	0.00	—1.6	3
175		12.67	6.59	2.50	—1.0	4
176		14.65	8.57	0.50	—1.4	4
177		15.67	9.59	0.00	—0.8	3
178		18.65	12.57	7.50	—1.1	0
179		19.67	0.67	7.00	—0.6	0

NO.	DATE 1908	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
180		26.60	7.60	2.75	—1.4	—
181		28.62	9.62	0.00	—0.8	—
182		29.62	10.62	0.75	—0.7	0
183		30.58	11.58	2.75	—1.6	0
184	Aug.	2.58	1.66	2.75	—0.9	0
185		9.58	8.66	1.00	—0.5	4
186		10.60	9.68	0.25	+0.1	4
187		11.60	10.68	0.00	+0.2	4
188		14.60	13.68(0.76)	5.50	+0.5	Moon faint
189		20.60	6.76	3.75	+0.8	0
190		23.56	9.72	0.00	±0.0	0
191		24.62	10.78	0.50	+1.5	0
192		27.65	0.89	5.50	+1.7	
193		28.56	1.80	1.00	+0.3	
194		29.62	2.86	0.00	+1.9	0
195		30.62	3.86	0.00	+1.9	0
196	Sept.	7.65	11.89	3.00	+1.7	3
197		8.62	12.86	7.00	+1.8	4
198		9.62	0.94	5.00	+1.9	4
199		10.62	1.94	0.00	+1.9	4
200		14.67	5.99	0.75	+3.2	2
201		16.56	7.88	0.25	+0.8	0
202		17.62	8.94	0.00	+2.4	0
203		18.62	9 94	0.00	+2.5	Sky thick
204		21.54	12.86	+7.75	+0.7	Sky thick
205		24.67	3.07	—0.50	+3.8	0
206		26.62	5.02	—0.00	+3.0	
207		27.62	6.02	+0.25	+3.0	
208		29.62	8.02	0.00	+3.2	0
209		30.62	9.02	—0.50	+3.3	
210	Oct.	1.67	10.07	—0.50	+4.3	0
211		2.62	11.02	+0.25	+3.4	0
212		3.60	12.00	3.50	+2.9	2
213		4.62	0.10	+7.00	+3.5	3
214		10.67	6.15	—0.25	+4.9	4
215		11.54	7.02	+2.75	+2.0	0
216		12.54	8.02	1.00	+2.0	0
217		12.69	8.17	0.25	+5.5	2
218		13.67	9.15	0.00	+5.1	2
219		14.67	10.15	—0.25	+5.2	2
220		15.67	11.15	—0 50	+5.3	1
221		18.58	1.14	+3.25	+3.4	0
222		19.67	2.23	0.00	+5.5	0
223		23.56	6.12	+0.75	+3.3	0
224		25.62	8.18	—0.50	+4.9	0
225		30.52	0.16	+7.25	+2.7	1
226	Nov.	1.58	2.22	+0.25	+4.2	2
227		2.54	3.18	—0.25	+3.4	2
228		3.54	4.18	0.00	+3.5	2
229		4.54	5.18	0.00	+3.6	2
230		6.52	7.16	+2.25	+3.2	4
231		8.50	9.14	—1.00	+2.8	
232		9.50	10.14	—0.25	+2.9	
233		11.54	12.18	+0.75	+4.0	
234		11.62	12.26	4.00	+6.0	2
235		12.52	0.24	8.25	+3.6	0

NO.	DATE 1908	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
236		12.62	0.34	7.75	+6.0	2
237		13.54	1.26	+1.75	+4.1	
238		14.52	2.24	0.00	+3.7	
239		15.50	3.22	—1.25	+3.3	0
240		20.50	8.22	0.00	+3.6	0
241		21.50	9.22	—2.00	+3.7	0
242		24.52	12.24	+2.75	+4.4	0
243		26.54	1.34	0.00	+5.0	0
244		27.50	2.30	—1.00	+4.0	—
245		28.50	3.30	—1.25	+4.1	1
246		30.54	5.34	0.00	+5.2	1
247	Dec.	1.52	6.32	+1.25	+4.8	1
248		2.60	7.40	1.50	+6.9	1
249		9.50	1.38	2.50	+4.8	4
	1909					
250	April	22.71	6.40	4.50	—5.3	—
251		25.69	9.38	0.50	—5.7	—
252		27.71	11.40	1.75	—5.0	—
253	May	7.67	8.44	3.50	—5.3	3
254		10.62	11.39	2.25	—6.2	0
255		12.67	0.52	8.50	—5.0	0
256		22.71	10.56	1.25	—3.4	0
257		28.67	3.60	0.50	—4.0	2
258		29.71	4.64	1.00	—2.9	2
259	June	1.71	7.64	1.25	—2.8	3
260		11.67	4.68	1.50	—3.1	0
261		13.62	6.63	5.00	—3.9	0
262		15.62	8.63	2.00	—3.8	0
263		16.62	9.63	3.00	—3.9	—
264		17.65	10.66	0.50	—3.4	—
265		18.65	11.66	0.50	—3.3	0
266		19.67	12.68	7.00	—2.7	0
267		20.65	0.74	7.00	—3.2	0
268		24.75	4.84	+1.00E	—0.2	0
269		24.75	4.84	—1.00W	—0.2	—
270		28.62	8.71	+0.50	—3.0	2
271		29.71	9.80	+0.50E	—1.2	3
272		29.71	9.80	—0.50W	—1.2	—
273	July	1.71	11.80	+4.00E	—0.9	4
274		1.71	11.80	2.00W	—0.9	
275		5.75	2.92	+1.00E	+0.5	—
276			2.92	—1.00W	+0.5	—
277		6.71	3.88	+1.00E	—0.4	3
278			3.88	—2.00W	—0.4	3
279		7.71	4.88	+1.00E	—0.3	2
280		7.71	4.88	—0.50W	—0.3	2
281		8.62	5.79	+3.25	—2.3	0
282		9.67	6.84	+6.75	—1.2	0
283		12.79	9.96	—1.50W	+2.0	0
284		15.75	0.00	+7.75E	—1.2	0
285		16.75	1.00	3.25E	—1.1	0
286		18.67	2.92	0.50W	—0.6	0
287		19.71	3.96	0.00SW	+0.4	0
288		21.71	5.96	0.00SW	+0.6	0
289		25.67	9.92	1.00W	—0.2	2

NO.	DATE 1909	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
290	Aug.	3.62	5.95	2.00E	—0.6	3
291		3.75	6.08	1.50W	—0.6	
292		4.75	7.08	+1.50W	+2.5	2
293		6.75	9.08	—1.00W	+2.6	2
294		8.67	11.00	0.00W	+0.7	0
295		20.71	10.12	0.00W	+2.5	0
296	Sept.	8.73	3.30	—0.50SW	+1.9	0
297		9.73	4.30	0.00SW	+2.0	0
298		10.73	5.30	+2.00SW	+2.1	0
299		11.79	6.36	5.00SW	+3.6	0
300		12.75	7.32	+2.00SW	+2.7	0
301		13.75	8.32	—0.50SW	+2.8	0
302		14.77	9.34	—1.00SW	+3.3	0
303		18.70	0.35	+8.50SW	+2.0	0
304		19.70	1.35	0.50SW	+2.1	0
305		20.73	2.38	0.50SW	+2.7	0
306		24.70	6.35	5.50SW	+2.4	2
307		25.70	7.35	+4.50SW	+2.5	3
308		26.70	8.35	—0.50SW	+2.6	3
309		28.73	10.38	0.00SW	+3.1	4
310		29.71	11.36	+0.50SW	+3.8	4
311	Oct.	5.56	4.29	0.00SW	+2.1	0
312		6.56	5.29	1.00SW	+2.2	0
313		14.71	0.52	8.50SW	+6.2	0
314		18.67	4.48	1.50SW	+5.4	0
315		30.62	3.52	0.00	+5.2	3
316	Nov.	3.58	7.48	1.00SW	+4.5	0
317		6.54	10.44	0.50	+3.7	0
318		10.50	1.48	2.50	+2.9	0
319		25.54	3.60	0.00	+4.9	4
320		26.58	4.64	0.50	+6.0	4
321		27.54	5.60	3.00	+5.0	4
322		29.58	7.64	+2.50	+6.2	3
323		30.54	8.60	—0.25	+5.2	0
324	Dec.	8.46	3.60	+0.12	+3.8	0
	1910					
325	April	13.73	0.67	6.75	—5.5	0
326	May	5.67	9.69	0.25	—5.5	0
327		12.71	3.81	1.00	—4.1	1
328		13.71	4.81	1.00	—4.0	1
329		14.63	5.73	2.00	—5.9	2
330		14.83	5.93	4.00	—0.9	—
331		15.83	6.93	6.00	—0.8	0
332		24.75	2.93	+0.00	—2.3	4
333		25.75	3.93	—0.25	—2.2	4
334		26.75	4.93	0.00	—2.1	3
335	June	5.71	1.97	+0.75	—2.5	0
336		6.67	2.93	0.00	—3.4	0
337		7.67	3.93	0.50	—3.3	0
338		9.67	5.93	2.50	—3.2	0
339		12.71	8.97	0.00	—2.0	0
340		15.67	11.93	1.50	—2.8	2
341		16.75	0.09	8.00	—0.8	3
342		18.71	2.05	1.50	—1.6	3
343		19.71	3.05	0.50	—1.5	3

NO.	DATE 1910	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
344		21.71	5.05	0.50	—1.4	4
345		22.75	6.09	2.50	—0.3	4
346		24.71	8.05	1.00	—1.2	4
347		27.67	11.01	0.50	—2.0	0
348		28.67	12.01	3.75	—1.9	0
349	July	4.67	5.09	1.00	—1.6	0
350		7.71	8.13	+1.00	—0.4	0
351		8.71	9.13	—0.50	—0.3	0
352		9.63	10.05	+0.00	—2.2	0
353		10.67	11.09	0.25	—1.2	0
354		12.71	0.21	8.25	—0.1	0
355		13.67	1.17	6.00	—1.0	2
356		17.67	5.17	0.50	—0.7	3
357		18.67	6.17	3.00	—0.6	4
358		19.67	7.17	3.50	—0.6	4
359		20.63	8.13	1.25	—1.5	4
360		24.63	12.13	3.25	—1.3	0
361		25.67	0.25	8.00	—0.2	3
362		27.67	2.25	+0.75	—0.1	0
363		28.67	3.25	—0.25	±0.0	0
364		29.71	4.29	+0.25	+1.1	0
365		30.63	5.21	3.50	—0.9	0
366		31.63	6.21	2.00	—0.8	0
367	Aug.	2.67	8.25	0.50	+0.3	0
368		3.63	9.21	+0.00	—0.8	0
369		4.63	10.21	—0.50	—0.7	0
370		5.67	11.25	+1.50	+0.5	0
371		6.58	12.16	1.50	—1.4	0
372		8.71	1.37	2.75	+1.7	0
373		10.67	3.33	0.50	+0.8	0
374		12.71	5.37	0.50	+2.0	0
375		18.67	11.33	0.50	+1.2	4
376		19.75	12.41	5.00	+3.2	4
377		20.71	0.45	8.00	+2.5	0
378		26.58	6.32	4.00	—0.1	0
379		27.58	7.32	3.00	±0.0	0
380	Sept.	7.63	5.45	0.50	+1.5	0
381		8.63	6.45	6.50	+1.6	0
382		14.71	12.53	6.00	+4.0	3
383		16.58	1.48	1.50	+1.1	4
384		19.63	4.53	0.00	+2.3	4
385		27.71	12.61	9.00	+5.0	0
386		28.71	0.69	8.00	+5.1	0
387		29.54	1.52	0.00	+1.1	0
388	Oct.	1.58	3.56	0.50	+2.3	0
389		2.54	4.52	0.00	+1.3	0
390		4.54	6.52	1.00	+1.5	0
391		6.67	8.65	1.00	+4.6	0
392		7.67	9.65	+0.50	+4.7	0
393		8.63	10.61	—0.50	+3.7	0
394		9.54	11.52	+0.50	+1.8	2
395		10.54	12.52	9.00	+1.8	2
396		11.54	0.60	9.00	+1.9	2
397		11.67	0.73	8.00	+4.9	2
398		13.67	2.73	0.00	+5.1	3
399		16.63	5.69	1.50	+4.3	
400		23.58	12.64	7.75	+3.7	0
401		25.50	1.64	0.75	+1.8	0
402		25.67	1.81	+0.50	+5.8	0
403		28.58	4.72	—0.50	+4.0	0
404		31.54	7.68	0.00	+3.2	0
405	Nov.	3.58	10.72	0.00	+4.5	0
406		4.50	11.64	+0.25	+2.5	0
407		4.63	11.77	0.75	+5.5	0
408		5.54	12.68	+7.50	+3.6	0
409		8.50	2.72	—0.25	+2.8	0
410		19.58	0.88	+4.50	+5.5	2
411		20.50	1.80	0.50	+3.6	0
412		26.50	7.80	+1.25	+4.0	0
413	Dec.	4.54	2.92	—0.25	+5.5	0
414		9.54	7.92	+0.50	+5.8	2
415		12.52	10.90	0.50	+5.5	2
416		20.52	5.98	1.00	+6.0	0
417		21.50	6.96	1.50	+5.6	0
418		23.50	8.96	0.00	+5.7	0
419		26.50	11.96	1.50	+5.9	0
	1911					
420	Apr.	16.67	6.86	5.00	—6.8	3
421		17.67	7.86	1.00	—6.7	0
422		22.71	12.90	8.00	—5.4	0
423		24.71	1.98	0.50	—5.3	0
424		25.71	2.98	0.00	—5.2	0
425	May	2.75	10.02	0.00	—3.7	0
426		3.75	11.02	1.00	—3.6	0
427		4.79	12.06	5.00	—2.6	0
428		5.75	0.10	7.25	—3.5	2
429		6.71	1.06	5.50	—4.5	2
430		7.75	2.10	1.00	—3.4	2
431		10.75	5.10	2.00	—3.2	3
432		12.71	7.06	4.25	—4.1	4
433		13.75	8.10	1.00	—3.0	4
434		17.71	12.06	4.50	—3.7	0
435		18.79	0.22	8.50	—1.7	0
436		23.71	5.14	2.50	—3.2	0
437		24.79	6.22	1.75	—1.3	0
438		25.75	7.18	3.50	—2.2	0
439		26.79	8.22	1.50	—1.1	0
440		30.75	12.18	2.75	—1.9	0
441		31.75	0.26	7.75	—1.8	0
442	June	1.75	1.26	2.50	—1.8	0
443		2.75	2.26	0.75	—1.7	1
444		5.75	5.26	0.50	—1.5	2
445		8.75	8.26	1.00	—1.2	3
446		9.71	9.22	0.50	—2.2	4
447		10.67	10.18	0.50	—3.2	4
448		11.75	11.26	0.50	—1.1	4
449		13.75	0.34	9.00	—1.0	3
450		14.67	1.26	5.50	—2.9	0
451		18.67	5.26	1.00	—2.6	0
452		19.71	6.30	1.50	—1.6	0
453		20.67	7.26	2.50	—2.5	0

NO.	DATE 1911	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
454		21.67	8.26	1.00	—2.4	0
455		22.67	9.26	0.50	—2.4	0
456		23.67	10.26	0.50	—2.3	0
457		26.71	0.38	7.50	—1.1	0
458		27.71	1.38	1.75	—1.0	0
459		28.71	2.38	0.00	—1.0	0
460		29.67	3.34	0.00	—1.9	0
461		30.67	4.34	0.00	—1.8	0
462	July	1.71	5.38	1.25	—0.8	0
463		3.67	7.34	3.50	—1.6	2
464		5.71	9.38	+0.50	—0.5	3
465		6.75	10.42	—0.50	+0.6	3
466		7.71	11.38	+1.50	—0.4	3
467		8.79	12.46	7.50	+1.7	
468		9.75	0.50	7.50	+0.7	
469		11.67	2.42	0.50	—1.1	4
470		11.79	2.54	0.00	+1.9	4
471		12.63	3.38	0.00	—2.1	0
472		13.71	4.46	0.50	±0.0	4
473		14.63	5.38	2.75	—1.9	0
474		17.63	8.38	2.25	—1.7	0
475		19.75	10.50	0.50	+1.4	0
476		20.67	11.42	1.50	—0.5	0
477		21.67	12.42	6.50	—0.5	0
478		22.71	0.54	6.50	+0.6	0
479		23.67	1.50	0.50	—0.3	0
480		26.67	4.50	1.00	—0.1	0
481		27.83	5.66	3.00	+3.9	0
482		28.67	6.50	2.5c	±0.0	0
483		29.67±	7.50	1.00	+0.1	0
484		30.63	8.46	0.50	—0.9	0
485	Aug.	4.63	0.54	8.00	—0.6	3
486		6.79	2.70	0.00	+3.6	4
487		8.67	4.58	0.50	+0.7	4
488		15.79	11.70	1.25	+4.2	2
489		17.58	0.57	8.00	—0.7	0
490		18.63	1.62	3.00	+0.4	0
491		19.75	2.74	0.00	+3.4	0
492		20.75	3.74	0.00	+3.5	0
493		28.75	11.74	1.00	+3.6	0
494		29.75	12.74	5.50	+4.1	0
495		30.75	0.82	6.00	+4.2	0
496		31.67	1.74	1.50	+2.2	2 low
497	Sept.	1.67.	2.74	+0.00	+2.3	2
498		2.63	3.70	—1.00	+1.4	2
499		3.67	4.74	+0.00	+2.4	3
500		5.67	6.74	+4.50	+2.6	3
501		9.63	10.70	—0.50	+1.8	4
502		12.63	0.78	+6.50	+2.0	2
503		13.67	1.82	1.50	+3.1	2
304		16.63	4.78	0.50	+2.3	0
505		17.58	5.73	0.75	+1.4	0
506		18.63	6.78	2.00	+2.4	0
507		23.67	11.82	1.50	+3.7	0
508		27.67	2.90	0.50	+4.0	0
509	Oct.	2.67	7.90	0.50	+4.3	3

NO.	DATE 1911	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
510		7.58	12.81	+7.50	+2.7	4
511		11.63	3.94	—0.50	+3.9	3
512		18.50	10.81	—1.00	+1.4	0
513		22.71	2.10	+0.00	+6.7	
514		25.54	4.93	+1.50	+2.8	0
515		27.71	7.10	3.50	+7.0	0
516		28.54	7.93	+0.00	+3.0	1
517		29.50	8.89	—0.50	+2.1	2
518	Nov.	8.50	5.97	+0.50	+2.8	3
519		15.58	0.13	8.25	+5.2	0
520		22.50	7.05	2.25	+3.7	0
521		29.50	1.13	+4.50	+4.1	2
522		30.54	2.17	—0.25	+5.2	2
523	Dec.	13.50	2.21	0.00	+5.1	0
524		22.50	11.21	0.00	+5.7	0
525		28.50	4.29	0.00	+6.2	2
	1912					
526	Mch.	16.83	6.10	+5.00	—4.8	0
527		19.79	9.06	0.00	—5.6	0
528		22.83	12.10	5.00	—4.4	
529		24.83	1.18	5.50	—4.2	0
530		26.75	3.10	0.50	—6.1	2
531		29.79	6.14	3.00	—4.9	3
532	April	5.75	0.17	8.00	—5.4	2
533		10.71	5.13	2.25	—6.1	0
534		14.75	9.17	1.50	—4.8	0
535		15.75	10.17	0.50	—4.8	0
536		24.79	6.29	4.00	—2.8	2
537		26.75	8.25	1.00	—4.1	3
538		27.71	9.21	0.50	—5.0	3
539		30.71	12.21	5.50	—4.8	4
540	May	8.79	7.37	3.75	—2.3	0
541		9.63	8.21	0.75	—6.3	0
542		14.71	0.37	6.75	—3.9	0
543		17.75	3.41	1.00	—2.7	0
544		24.79	10.45	0.50	—1.2	2
545		25.67	11.33	0.50	—4.2	3
546		30.75	3.49	0.25	—1.8	4
547		31.75	4.49	0.00	—1.8	4
548	June	2.71	6.45	4.50	—1.6	0
549		4.67	8.41	0.50	—1.5	0
550		6.75	10.49	0.50	—1.4	0
551		8.75	12.49	6.75	—1.2	0
552		9.67	0.49	7.50	—3.2	0
553		10.75	1.57	4.50	—1.1	0
554		13.79	4.61	0.25	+0.1	0
555		21.75	12.57	6.50	—0.4	2
556		22.71	13.53	7.00	—1.3	2
557		30.67	8.57	1.25	—1.8	4
558	July	2.67	10.57	0.50	—1.7	0
559		3.75	11.65	0.50	+0.4	2
560		6.67	1.65	2.00	—1.4	0
561		9.71	4.69	2.00	—0.2	0
562		10.71	5.69	0.50	—0.1	0
563		11.71	6.69	3.50	—0.1	0
564		17.71	12.69	5.00	+0.3	0

NO.	DATE 1912	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
565		18.67	0.73	7.25	—0.6	0
566		22.67	4.73	1.50	—0.3	2
567		29.58	11.64	2.25	—1.9	0
568		31.71	0.85	6.50	+1.2	2
569	Aug.	2.67	2.81	0.50	+0.4	2
570		6.67	6.81	5.00	+0.6	0
571		11.67	11.81	0.00	+1.0	0
572		15.67	2.89	0.00	+1.2	0
573		20.71	7.93	+0.50	+2.6	0
574		21.75	8.97	—1.00	+3.6	0
575		26.63	0.93	+4.50	+1.0	4
576	Sept.	3.58	8.88	+0.50	+0.4	0
577		5.67	10.97	—0.50	+2.5	0
578		6.58	11.88	+0.50	+0.6	0
579		7.58	12.88	5.75	+0.6	0
580		8.58	0.96	5.00	+0.7	0
581		9.58	1.96	0.50	+0.8	0
582		11.58	3.96	0.00	+0.9	0
583		12.58	4.96	0.00	+1.0	0
584		15.63	8.01	+0.00	+2.2	0
585		18.63	11.01	—0.50	+2.4	1
586		22.67	2.13	—0.25	+3.6	2
587		23.63	3.09	—1.00	+2.7	3
588		26.63	6.09	+1.00	+2.9	4
589		29.67	9.13	0.00	+4.2	3
590	Oct.	1.67	11.13	0.25	+4.3	2
591		2.58	12.04	0.50	+2.4	0
592		4.58	1.12	0.50	+2.5	0
593		5.67	2.21	+0.00	+4.6	0
594		12.67	9.21	—0.50	+5.0	0
595		13.71	10.25	+0.00	+6.1	0
596		16.58	0.20	8.25	+3.3	1
597		19.63	3.25	0.00	+4.5	2
598		20.54	4.16	0.50	+2.6	3
599		24.58	8.20	0.50	+3.8	4
600		26.67	10.29	+0.50	+6.0	4
601	Nov.	7.50	9.20	—0.50	+2.7	0
602		10.54	12.24	+1.50	+3.9	0
603		15.50	4.28	—0.25	+2.9	1
604		20.50	9.28	0.00	+3.6	3
605		27.50	3.36	—0.50	+4.2	0
606		30.46	6.32	+3.00	+3.3	0
607	Dec.	4.46	10.32	—0.25	+3.5	0
608		7.50	0.44	+7.50	+4.7	0
609		7.50	0.44	$\beta=\zeta$	+4.7	
610		9.50	2.44	0.00	+4.8	0
611		12.50	5.44	0.00	+5.0	1
612		14.50	7.44	+2.50	+5.2	2
613		17.50	10.44	—0.25	+5.4	2
614		22.50	2.52	+1.00	+5.7	4
615		28.50	8.52	0.00	+6.1	0
	1913					
616	Jan.	4.50	2.60	0.00	+6.6	0
617		8.50	6.60	2.25	+6.8	0
618		9.50	7.60	1.25	+6.9	0
619	Feb.	8.87	12.13	+4.25	—6.1	0

REDUCTIONS.

In the reductions the observations of each year were first treated separately in order to bring out any changes in the light curve. The light estimates for each year were arranged in order of phase and were combined into normal places in groups of from three to six observations. These results for all six years were then plotted on a large scale upon one graph in a manner calculated to facilitate the detection of variations from year to year.

As no yearly variations were surely established the entire set of 612 observations was then reduced in the same manner, the resulting normal places containing from eight to eleven observations but in most cases ten, as indicated in Table II. The resulting sixty-one mean values of the brightness of β Lyrae were plotted against the corresponding phase times and through the points so determined the preliminary light curve was drawn.

The residual for each of the original single estimates was then scaled off from this curve. These residuals with the corresponding hour angles were arranged in order of increasing hour angle and were combined into eighteen normal places each of which furnished a value of the mean residual, from the mean curve, corresponding to a mean hour angle. These normal places supplied the data from which the preliminary hour angle correction curve was directly drawn. However it was soon apparent that the amplitude of the hour angle correction curve, giving the error affecting any light estimate due to the relative position of the stars in the sky, depended on the brightness of the variable. Very probably when the variable was faint the star, δ Lyrae, was taken more directly into account in the observations and its position with reference to the variable entered more directly into the result. Accordingly the observations were divided into three classes; those within a step and a half of γ Lyrae, those between one and a half and four steps fainter than γ Lyrae, and those more than four steps fainter than γ Lyrae. For each of these classes the error curve depending upon hour angle was then determined. Finally the

correction to each one of the original 612 estimates was taken from the proper hour angle error curve and from these the corresponding correction to each of the original sixty-one normal places was derived.

At this point the probable error of a single estimate of the brightness of the variable was determined for an observation in each of the three classes of observations mentioned above. And on the basis of these probable errors six of the original observations were rejected in accordance with a careful application of the usual criterion.

As a final measure, to examine the effect on the light curve of any chance grouping of the observations in the normal places, new means were formed in which the single estimates were combined in groups of five. And also a new set of normal places containing ten observations each were formed by combining the first five observations of each of the original normal places with the last five of the preceding normal place.

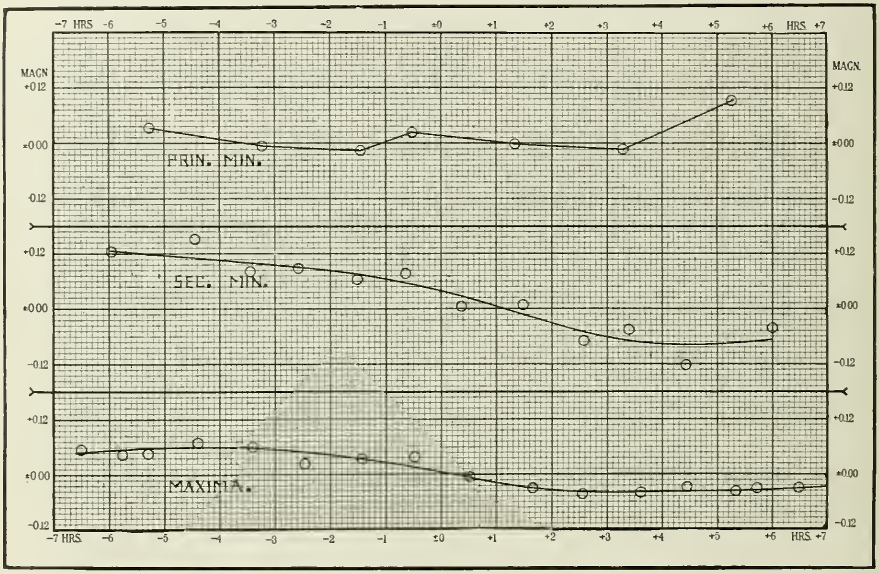


Plate XV. Curves Exhibiting the Hour Angle Effect upon Estimates of the Brightness of β Lyrae.

THE RESULTS.

The curves representing the character and extent of the variation, with changing hour angle, of the apparent brightness of β Lyrae referred to the comparison stars are reproduced in Plate XV. Horizontally the large squares on the diagram represent hours of hour angle; vertically they represent one of the units (0.12 magn.) used in the light comparisons. Originally the observations of the first as well as the second light maximum were reduced separately but the resulting curves were so nearly identical that it was considered best to combine them into one graph. The lower curve, therefore, is based upon all the observations of the variable within one and one-half steps of γ Lyrae. The second curve results from a study of the observations near secondary minimum and at the phases before and after principal minimum when the brightness of the variable was in the neighborhood of that at secondary minimum. The upper curve is based on the observations near the principal minimum.

A study of these curves indicates that the double amplitude of this effect is about eight one-hundredths of a step or about one-tenth of a magnitude when the variable and comparison star are of nearly the same brightness. As the difference in brightness of comparison and variable becomes larger the amplitude of this curve seems to increase very markedly. But when the variable becomes comparable in brightness with the fainter comparison star lying in a new direction there seems to be no well established dependence of the errors of estimations upon hour angle changes. Thus it is evident that this effect is a complicated one related very probably to the distance between the two compared stars, the relative brightness of the two stars, and the angle between the line joining the two stars and a vertical line passing through a point midway between them. Also this effect includes differences due to variation of the relative atmospheric absorption of variable and comparison stars with changing hour angle.

In any given case, it will be difficult to eliminate this effect, especially when, as in Argelander's method, different comparison stars are given the greatest weight in the comparisons in different parts of the light curve. In general in a series of observations of a short period variable extending over a period of years the errors arising from this source may be considered as accidental. In the present case the original observations, as stated above, have been corrected for this error on the basis of the curves determined. But even here it is readily seen that the effect is not entirely corrected for and that very small relative shifts in different parts of the final light curve may result from the variation of the magnitude of the hour angle error with the brightness of the variable and also from the fact that the observer cannot follow the stars during their motion entirely around their diurnal circles.

The mean observed brightnesses of β Lyrae, corrected for hour angle effect,* are given with their corresponding phases in Table II. The first column contains the phase reckoned from principal minimum; the second, the mean brightness in steps referred to γ Lyrae; the third, the corresponding magnitudes referred to γ Lyrae which is assumed to be 1.22 magnitudes brighter than δ Lyrae. The fourth column gives the number of observations entering into each mean and the fifth the residuals from a smooth mean curve.

* This correction is taken from the lower curves of plate XV.

TABLE II.—NORMAL PLACES.

PHASE	MEAN COMPARISON STEPS	MAGN.	OBSERVATIONS	RESID. MAGN.
0.138	+7.85	+0.958	10	—0.008
0.281	7.70	0.939	10	+0.008
0.427	7.60	0.927	10	+0.011
0.562	7.65	0.933	10	—0.013
0.728	6.95	0.848	10	—0.014
0.926	5.50	0.671	10	+0.001
1.204	3.70	0.451	9	+0.020
1.407	3.07	0.375	10	—0.035
1.547	2.03	0.248	10	+0.004
1.723	1.41	0.172	9	—0.002
2.025	0.51	0.062	10	—0.019
2.225	0.41	0.049	10	+0.003
2.410	0.17	0.021	10	+0.006
2.667	0.41	0.050	10	—0.029
2.917	+0.06	+0.007	10	+0.004
3.154	—0.14	—0.017	11	+0.018
3.363	—0.05	—0.006	11	+0.006
3.611	+0.22	+0.027	10	+0.022
3.807	—0.09	—0.010	11	+0.026
4.264	+0.40	+0.049	10	—0.012
4.460	0.44	0.054	10	—0.001
4.607	0.50	0.061	10	+0.007
4.784	0.64	0.078	10	+0.003
5.003	0.64	0.078	10	+0.027
5.251	1.21	0.148	10	—0.011
5.485	1.51	0.184	10	—0.016
5.774	2.06	0.251	10	—0.036
5.903	1.52	0.185	10	+0.085
6.140	2.32	0.283	10	—0.028
6.293	3.15	0.384	10	±0.000
6.444	3.82	0.466	10	—0.031
6.630	3.36	0.410	10	+0.048
6.847	4.06	0.495	10	—0.043
7.118	2.64	0.322	10	+0.054
7.310	2.47	0.301	10	+0.012
7.437	2.45	0.299	9	+0.037
7.636	1.84	0.224	8	—0.027
7.885	0.86	0.105	10	+0.033
8.102	0.77	0.094	10	+0.005
8.231	0.69	0.084	9	+0.001
8.400	0.37	0.045	10	+0.019

PHASE	MEAN COMPARISON STEPS	MAGN.	OBSERVA-TIONS	RESID. MAGN.
8.605	0.64	0.078	9	—0.032
8.938	+0.19	+0.023	11	±0.000
9.163	—0.05	—0.006	10	+0.018
9.272	—0.11	—0.013	10	+0.021
9.493	+0.26	+0.032	10	—0.032
9.727	+0.01	+0.002	10	—0.004
9.996	—0.11	—0.014	10	+0.015
10.154	—0.14	—0.017	10	+0.022
10.331	+0.33	+0.040	10	—0.028
10.485	0.45	0.055	10	—0.035
10.690	0.27	0.033	11	+0.004
11.029	0.29	0.035	10	+0.036
11.273	0.63	0.077	11	+0.023
11.508	1.31	0.160	10	—0.020
11.728	1.33	0.162	10	+0.035
11.949	2.47	0.302	10	—0.020
12.156	3.23	0.394	10	+0.020
12.389	5.52	0.674	10	—0.005
12.586	7.36	0.898	9	+0.019
12.826	+7.56	+0.922	9	+0.010

The phases and corresponding magnitudes in this table are plotted in Plate XVI, upper curve. The magnitudes indicated on the margins of this plate apply only to the upper curve and correspond to a magnitude of 3.30 for γ Lyrae, and 4.52 for δ Lyrae.

To exhibit any minor irregularities that may be present in this curve the successive points have been connected throughout. And to determine the bearing of any chance grouping of the observation in forming normal places the original observations have been combined in two other different ways as described above. The new normal places thus found show that the first set represents the observations very satisfactorily though some minor changes in the small features of the curve would result if the parallel mean brightnesses were used.

In Plate XVI a smooth mean curve has been drawn through the observations. Corresponding to this mean curve, the relative phase times and the magnitudes at the principal phases are found in Table III which also contains similar data obtained from the observations of separate years. The phase times refer to principal minimum as computed by Pannekoek's revised formula.

TABLE III.—MAGNITUDES AND RELATIVE TIMES OF PRINCIPAL PHASES.

YEAR	PRINCIPAL MINIMUM PHASE		FIRST MAXIMUM PHASE		SECONDARY MINIMUM PHASE		SECOND MAXIMUM PHASE	
	DAYS	MAG.	DAYS	MAG.	DAYS	MAG.	DAYS	MAG.
1907	0.10	4.29	3.34	3.30	6.67	3.71	9.90	3.32
1908	0.10	4.25	3.35	3.28	6.76	3.68	9.65	3.28
1909	——	4.29	3.55	3.29	6.56	3.84	9.77	3.31
1910	0.16	4.31	3.48	3.30	6.57	3.76	10.17	3.30
1911	0.16	4.28	3.48	3.28	6.65	3.78	10.07	3.30
1912	0.14	4.29	3.50	3.29	6.58	3.77	10.06	3.30
1907–12 Mean	0.13	4.27	3.45	3.29	6.63	3.76	9.94	3.30
Curve	0.16	4.245	3.34	3.300	6.68	3.745	9.69	3 297

From Table III it is evident that the variation in the magnitude at any principal phase in different years is very small; not exceeding 0.06 magnitudes except at the secondary minimum. There is also good agreement with the results in the last line obtained from the final mean curve. In the case of the secondary minimum, variations of magnitude from one year to another amount to 0.16 magn. It should be stated that the accuracy of my observations is least at this phase but it is also interesting to recall that other observers, notably Schmidt, have noted large variations in the magnitude of β Lyrae at the secondary minimum. In my final mean magnitude observations near this phase, these variations are reflected in relatively large irregularities, to which certain minor oscillations in my light curve are attributable.

It is interesting to note that the magnitude differences between β Lyrae and γ Lyrae at the principal phases as determined by the writer agree well with the corresponding results for yellowish green light interpolated from Nordman's observations in blue, yellow and red light. But in general the results of different observers in absolute magnitude are found to differ greatly, largely no doubt because of the differences among the magnitudes assumed for the comparison stars.

It will be noted that the relative times of the principal phases are uncertain. This follows from the nature of the case. That there are no real changes established here is evident from the difference between the phase times determined from

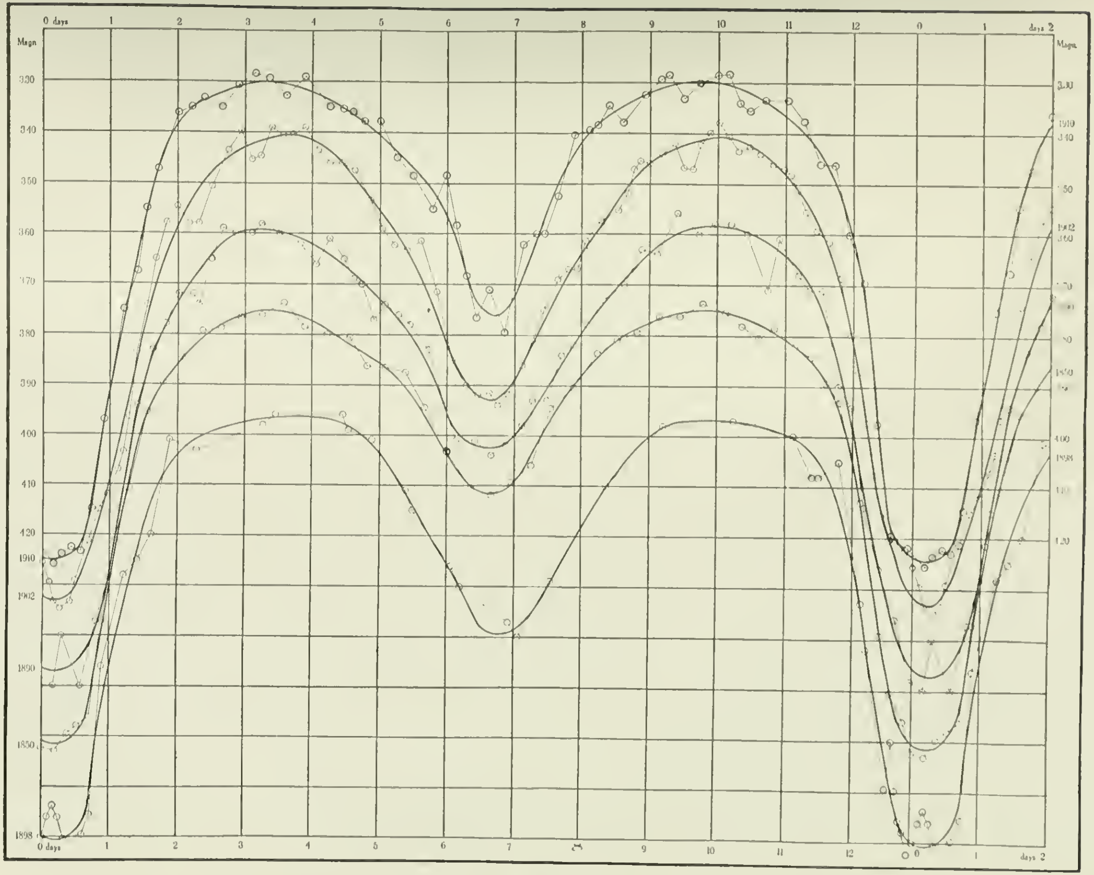


Plate XVI. Light Curves of β Lyrae.

the mean of the yearly values and the same phase times taken from the mean curve.

At the same time a correction to the time of principal minimum as predicted on the basis of Pannekoek's revised formula seems to be well established. For the epoch 1910.0 this correction is + 0.15 days.

COMPARISON OF RESULTS OF DIFFERENT OBSERVERS.

Probable Errors.

Though the general accuracy of the present results may be estimated well from the curve of Plate XVI, a statement of the probable errors may have some bearing on the reality of the minor irregularities and will serve to furnish an indication of the accuracy of the observing method used here as compared with that of Argelander as usually employed.

The probable error of a single comparison near maximum light in the present series of observations is ± 0.37 steps or ± 0.045 magn. The same quantity near secondary minimum brightness is ± 0.80 steps or ± 0.098 magn.; and near principal minimum it is ± 0.52 steps or ± 0.063 magn. Thus the probable error of a mean of ten estimates may be obtained for any part of the curve. A mean value of the probable error of a normal place for the whole curve obtained from the residuals in Table II is ± 0.13 steps or ± 0.016 magnitudes. In all cases the residuals refer to the smooth curve. They would be somewhat reduced if an irregular curve were used. Argelander's value for the probable error of his single determinations was ± 0.063 magn. and Schönfeld's was ± 0.054 magn., in good agreement with the mean of my values.

It will be seen that the probable error of a single observation in the present series is relatively great when the brightness of the variable is near that of the secondary minimum. This is perhaps partly due to actual irregularities in the variation of β Lyrae at secondary minimum but is probably largely due to the difficulty in estimating large differences in relative brightness. The method of comparison used in this set of observations was adopted, after some experimentation, with the hope that the relative nearness of the comparison stars would compensate for the greater differences between the brightness of the variable and that of one or both of the comparison stars. The results indicate that this is the case on the average and seem to show that for a variable with a range not exceeding seven or eight-tenths of a magnitude this method might give more accordant results than one employing several scattered standards, when two suitable comparison stars near the variable are available.

Principal Phases of the Light Curve.

In a study of the intervals between the principal phases in the light curve of β Lyrae, Pannekoek has discussed all of the more important sets of observations before 1896 in order to test the reality of variations in these intervals suspected by Lindemann.

In Table IV, most of the visual results which have been published to date have been used in the determination of these intervals from principal minimum to the other principal phases. In this table the results at the first epoch are based upon Goodricke's observations only; but those for the second epoch depend upon observations of Argelander, Schönfeld, Oudemans and Schmidt; the third, upon the work of Schmidt, Sawyer, Schur, Schwab, Plassmann, Pannekoek, Glasenapp and Menze. The results of the several individuals in later years are then given. And finally for the interval, 1892-1912, the results of the seven named observers are combined into one mean. Apparently no variations in these intervals are established.

TABLE IV.—INTERVAL BETWEEN PRINCIPAL MINIMUM AND THE OTHER PRINCIPAL PHASES.

EPOCH.	OBSERVER	1ST MAX.	2ND MIN.	2ND MAX.
1784	Goodricke	3.58 days	6.38 days	9.58 days
1842–1870	Mean	3.12 ±0.013	6.40 ±0.017	9.54 ±0.055
1870–1895	Mean	3.30 ±0.036	6.48 ±0.026	9.73 ±0.055
1892–1902	Beliawsky	3.22	6.59	9.65
1895–1897	Stratonow	3.07	6.40	9.44
1896–1905	Markwick	3.62	6.37	9.75
1897–1900	Wendell	3.40	6.58	9.68
1898–1906	Luizet	3.34	6.37	9.72
1902–1908	Lau	3.40	6.46	9.75
1907–1912	Curtiss	3.18	6.50	9.53
1892–1912	Mean	3.32 ±0.052	6.47 ±0.028	9.65 ±0.033

The Form of the Mean Light Curve.

In order to facilitate the study of the form of the mean light curve, together with its possible changes, the writer has placed in parallel with his own, in Plate XVI, the results obtained from several representative series of observations corresponding to different epochs.

The earliest curve is that of Argelander. This is derived from 1439 single observations made in the years 1844-1859. Thus the separate means depend upon thirty observations and the average range of phase covered by the observations in any mean is about 0.30 days.

The next curve in order of time (third from the top of the plate) is based upon about 1700 observations made in the years 1877-1897 by Schur, Plassmann, Pannekoek, Glasenapp, Menze and Stratonow. In combining the results of these different observers Stratonow has given his own 634 observations a weight of four; Menze's, a weight of one; and the remaining observations, a weight of two. Thus Stratonow's observations, covering a period of only three years, have a great influence on the final curve. The sixty-one mean magnitudes upon which this curve depends, are each derived from about twenty-eight single observations with a range of phase of about 0.20 days.

Wendell's 221 photometric observations (1897-1900) were used to determine the lower curve of Plate XVI. Except near the principal minimum the plotted points depend upon three or four observations only but near the chief minimum they represent means of from eight to ten single observations. Except for one case, the phase covered by any mean does not exceed 0.15 days.

The more recent curve (1898-1906) of Luizet is the second on Plate XVI. 844 observations are used to form the 84 means corresponding to the plotted points. Using the well known method of overlapping means, twenty observations are combined in each group. Thus each of the original observations is used twice and the average range of phase over which the observations of any mean extend is 0.30 days.

The upper curve represents the writer's observations of the years 1907-1912. The sixty-one plotted points each depend upon ten observations on the average and the average phase interval covered by each is about 0.18 days.

In adjusting these four representative curves to parallelism with my own, the attempt has been made to move them along the time axis in such a way that a considerable section of the curve at the principal minima, and not the absolute minima alone, should be brought into average coincidence. Whenever magnitudes were available the results were platted as furnished by the observer, without alteration of scale, the vertical squares on the diagram representing tenths of a magnitude. Thus the range of the first (the writer's) curve is 0.96 magnitudes; that of the third (Stratonow's) curve, 0.89 magnitudes; and that of the fifth (Wendell's) curve, 0.85 magnitudes. And the vertical scale of the second (Luizet's) and the fourth (Argelander's) curves, for which the results were published in steps, has been made intermediate with respect to the curves between which they are placed on Plate XVI.

The Decrease in Brightness of Secondary Minimum.

The decrease in the brightness of secondary minimum referred to the brightness at maxima has been noted by Luizet who finds the rate of this decrease to be about 0.1 of a magnitude in fifty years. The curves of Plate XVI exhibit this effect and indicate that a progressive sharpening of the curve at this phase is also a possibility, The data bearing on this effect from the two new curves of Plate XVI have been added to those already discussed by Luizet, to form Table V. The scale of each curve has been reduced to that of the third (Stratonow's) curve of the diagram, the total range being 0.89 magn.

TABLE V.—DIFFERENCE IN BRIGHTNESS BETWEEN MAXIMA AND SECONDARY MINIMUM.

Year.	Observer.	Max.—Sec. Min. Magn.
1850	Argelander	—0.37
1863	Schönfeld	0.37
1881	Schur	0.44
1890	Plassmann	0.39
1894	Pannekoek	0.44
1897	Glasenapp	0.50
1897	Stratonow	0.45
1898	Wendell	0.45
1902	Luizet	0.50
1910	Curtiss	—0.43

The Shape of the Maxima.

We may also consider the curves of Plate XVI in connection with Roberts' remark of 1906, "Thus, recent light curves are flatter at maxima than those found by Goodricke and Argelander." As the curve of Goodricke was not very well determined it is perhaps unwise in studying small changes to give much weight to any light curves which antedated the very similar ones of Heis and Argelander the latter of which has never been surpassed in accuracy. In connection with Argelander's curve the several other curves of Plate XVI would seem to throw light upon the point in question.

It is evident that the maxima of Stratonow's curve of 1877 to 1897, based upon the results of six observers are sharper than those of Argelander, and Luizet's curve of 1902 is still sharper. The first maximum of Wendell's curve of 1898 resembles Argelander's very closely but the second maximum of Wendell is sharper than Argelander's. My own curve of 1910 is perhaps flatter than Argelander's at the maxima. I am inclined to ascribe these differences to the tendency, discussed above, to which all observers are probably subject, of underestimating the difference in brightness of two stars of nearly the same magnitude. On comparisons of β with γ Lyrae near the maxima of the variable this source of error has undoubtedly exercised some influence, varying in extent with different observers. The curves of Plate XVI indicate that this may be the case and seem to permit of no definite conclusions as to real variations in flatness of the maxima.

Minor Irregularities.

In drawing the smooth light curve of β Lyrae it seems difficult to avoid introducing a slight subordinate maximum between five and six days after the principal minimum. This was noted by Lindemann and seems to be a well established feature of this curve, though the deviation from a smooth curve does not exceed two or three hundredths of a magnitude.

In addition to this small irregularity in the light curve of this star, Lindemann and Pannekoek have suspected the physical reality of other excursions of the observed brightness of this variable above and below a smooth curve. Stratonow considers ten of these irregularities certain and Luizet finds nine minor oscillations of the light curve to be well established, three others fairly certain and a thirteenth suspected. Three of these he finds persisting in the observations from 1784 to 1906. Six others were observed over nearly a hundred years.

The character of the oscillations in question is well shown in each of the curves in Plate XVI. Since the period of these minor oscillations is roughly of the order of one day it will be noted that in one respect the curves of Stratonow, Wendell, and the writer should serve to bring out these irregularities best, for the range of phase covered by the observations in each mean is smaller than in the cases of the other curves. But all the curves of Plate II are of importance in this connection.

It is therefore interesting to note that in Argelander's curve, which is probably the strongest known, the extent of these excursions is the least. It is also noteworthy that the combination of Stratonow's own observations with those of other observers reduced the average amplitude of the minor oscillations in his curve and probably would have done so to a greater extent if the observations of the others had been given the same weight as his own. It would seem to be the case that, if the curves of Plate XVI were combined into one mean curve, few if any of the minor oscillations would survive. In general there seems to be no established synchronism in the occurrence of these oscillations in different curves.

On the other hand there seem to be some resemblances between the minor oscillations of different curves, which are hard to explain as accidental. Thus, beginning at the minor maximum of phase, 10 hours, which is found well defined in the curves of Luizet and the writer, and following these two curves back to the first maximum it will be seen that very similar irregularities occur in both curves, not in synchronism, but *in an interesting symmetrical relation with respect to the secondary minimum.* Other resemblances between different curves raise interesting questions. Probably some resemblances are acci-

dental. Possibly some are real. But it would seem that the whole question must await the evidence of photometric observations or perhaps of visual comparisons secured through the coöperation of a number of observers.

THE REALITY OF CHANGES IN THE LIGHT CURVE.

The opinion of some observers seems to be that while the minor irregularities persist for long periods of years, there are well marked changes in the form of the general light curve from one epoch to another. These changes, both in the maxima and minima, have been discussed above and may be seen at a glance in Plate XVI. They are usually small in extent. In most cases they could not be established through the visual observations of one observer in two years. They seem reliable only when based upon long means. In view of the personal, systematic errors which enter into these means it would seem that the reality of many of the observed changes in the light curve of β Lyrae may not be regarded as established. And suspected changes in the elements of the system derived from the light curve are to be announced with caution. It seems not improbable, as Keeler found in the case of spectroscopic observations of this star, that more refined methods will show that the light variation of β Lyrae in the thirteen-day period is repeated with less irregularity than present results might lead us to think.

SUMMARY.

In the present paper the errors affecting visual light comparisons of stars are first discussed. And a method, employing but two comparison stars, is adopted in the hope that some of these errors may be varied if not controlled.

Six hundred and twelve observations made by this method are given in detail and are reduced, for the determination of the light curve, in a manner calculated to bring out and partly eliminate the effect upon the apparent relative brightness of two stars due to their relative position in the sky.

The light curve of β Lyrae for each year from 1907-1912 is determined and also a mean curve for this whole period is drawn. A correction, at the epoch, 1910.0, of $+$ 0.15 days is found for the time of principal minimum as predicted on the basis of Pannekoek's revised formula.

Among the writer's own curves in different years and among the writer's curve and those of other observers there are seen to be few if any established physically real differences. The relative intervals between the principal phases can not be said to change. The range of brightness from the maxima to the principal minimum is difficult to establish; but if this be considered constant for different observers the relative brightness at secondary minimum appears to be decreasing. A change in the form of the maxima involving increase in flatness in recent curves does not seem to be supported by the evidence collected here.

There seems to be some evidence of the reality of one persistent minor irregularity in the curve of β Lyrae. The reality of a number of others which have been suspected, is made to appear uncertain. The physical reality of many of the observed changes in the light curve of β Lyrae is questioned.

As the method of observation employed here by the writer seems to yield results comparable in accuracy with those obtained by other applications of Argelander's method, the work is being extended to other stars in the hope that information may be gained with reference to personal, systematic errors, which may help in the determination of the visual light curves of these interesting objects.

1913.

SOME POSSIBLE CHARACTERISTICS OF CEPHEID VARIABLE STARS*

By RALPH H. CURTISS

Though the list of announced characteristics of Cepheid variables is a long one, no satisfactory solution of the problem of the light variations of these stars seems to be in sight. Further information is needed in connection with the extension of old discussions, and new relations bearing upon the problem of Cepheid light variation are of great interest.

DISTRIBUTION BY PERIODS.

Attention has been called by Campbell and others to the relative preponderance of Cepheid stars with periods between certain limits. Campbell's deductions from fifty-three cases are well borne out by the ninety-three stars of this class included in the latest list of Luizet. In this list[1] it is possible that certain ellipsoidal variables have been included, but for the present it seems difficult or impossible to exclude them and their influence on the result will be small if not negligible. Probably some antalgol stars are also found here, especially among those with periods less than one day. The intentional inclusion of antalgol stars may prove desirable when more is known about them. SV Geminorum is to be excluded as an Algol star.

In this list compiled by Luizet there are thirteen stars with periods less than half a day. Eight have periods between 0.5 days and one day; two, between one day and two days; two, between two and three days; five, between three and four days; eight, between four and five days; seven, between five and six days; nine, between six and seven days; and eight, between seven and eight days. At this point the number of stars decreases sharply with increasing period. Only two are known with periods between nine and ten days. Above this limit this relative scarcity of known cases becomes more marked up to periods of twenty days from which point the Cepheids known are thinly distributed up to the present limit of 41.3 days. Considerably more than one-third of all known Cepheid variables have light periods between three and eight days. Nearly one-quarter of all Cepheid variables have periods less than a day.

These relations are shown graphically in the curve of Plate XVII, in which the relative number of stars with periods within a limit of one day are plotted with appropriate mean values of the period as abscissae. The determination of the points so plotted calls for certain rather arbitrary decisions such as are ordinarily met with in forming normal places but the form of the curve is well substantiated.

The curve of Plate XVII would seem to indicate that these stars may be divided into two groups: one with a preference for periods of four to eight days but possibly including variables with periods up to 100 days; the other, with periods less than two days. However the apparent division between these groups may not be a real one, for scarcity of known Cepheid variables with periods of one to three days may be due to difficulties attending the discovery of these stars because of their smaller magnitude range as shown on Plate XVIII.

PERIOD AND MAGNITUDE RANGE.

For the study of the relation between variation period and magnitude range in Cepheid variables the available material seems fairly adequate. And for the purpose I have adopted Luizet's list of ninety-three stars cited above. The data derived from Luizet's list are found in Table I. In this study the stars in this list were first arranged in order of periods. And for

* Note added Feb. 10, 1915. In order to avoid further delay in the publication of this paper, which has been in press for a long time, no discussion or revision is attempted on the basis of contributions which have come to hand since August 1, 1913, when the paper was completed.

[1] *Luizet. Annales de L'Universite de Lyon. Nouvelle serie. I, 33 pp. 3-5.*

groups of stars with periods ranging between selected limits, direct means of the periods and corresponding magnitude ranges were taken. These average periods are found in the first column of Table I, and in the second column appear the corresponding limits within which lie the periods entering into each mean. The mean magnitude range and its probable error are found in the third and fourth columns of this table. The data of the first and third columns of Table I are plotted in Plate XVIII with periods as abscissae.

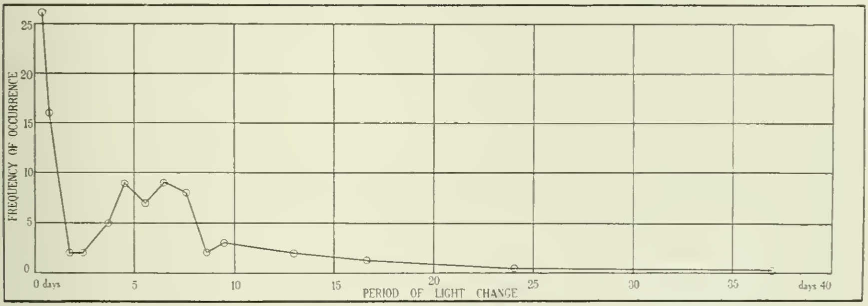


Plate XVII. Graphical Representation of the Relation Between Frequency of Occurrence and Period in Cepheid Variables.

TABLE I. PERIOD AND MAGNITUDE RANGE IN CEPHEID VARIABLES.

MEAN PERIOD days	LIMITS OF PERIOD days days	MAGNITUDE RANGE magn.	PROBABLE ERROR magn.	NO. OF STARS
0.31	0.00 — 0.44	0.86	±0.09	7
0.47	0.45 — 0.50	0.97	0.12	6
0.72	0.50 — 1.00	0.82	0.05	8
2.08	1.00 — 3.00	0.65	0.10	4
3.70	3.00 — 4.00	0.70	0.08	5
4.51	4.00 — 5.00	0.96	0.06	9
5.55	5.00 — 6.00	1.07	0.15	7
6.44	6.00 — 7.00	1.06	0.09	9
7.63	7.00 — 8.00	1.06	0.11	8
8.94	8.00 — 10.00	1.08	0.15	6
12.98	10.00 — 15.00	1.14	0.07	10
16.57	15.00 — 20.00	1.18	0.09	6
29.	20.00 — 41.31	1.26	0.07	8

In view of the determinate character of the plotted points there seems to be little question as to the physical reality of the variation indicated. Possibly the small indicated increase in magnitude range with increasing periods up to 0.5 days is not real. But the rapid decrease of magnitude range with increasing periods from 0.5 days to 2.0 days seems well established and the rapid increase of magnitude range for periods increasing from 3.0 to 6.0 days is hardly to be questioned. From this point on, the average magnitude range increases by approximately 0.1 magnitudes for each ten days' increase of the period of light variation but with a tendency toward a decrease, for greater periods, in the ratio of change in magnitude range to increase in period.

It should be noted also that the use of the photometric data by Pickering in Volume 46 of the *Harvard Annals* would introduce a second minimum in the curve corresponding to periods between seven and eight days. This is attributable to a tendency toward relatively smaller range for the average case as derived from Pickering's results. Though the accuracy of Pickering's values probably exceeds that of the data relative to magnitude range in Luizet's list, it has seemed best for the sake of homogeneity to exclude the Harvard results.

It would seem that the curve of Plate XVIII must depend upon several factors. For stars with periods in the neighborhood of six days the magnitude range is about 1.05. For longer periods the increase in the corresponding magnitude range may be due in part to the diminished

chance of discovery of a variable star of smaller range as the period increases. As the period decreases to two days the magnitude range decreases sharply, possibly because of a greater relative brightness of the secondary or fainter component of the system, the variations of which may be opposite in phase to those of the primary. Finally as the period decreases from two days, the magnitude range increases rapidly possibly because of effects associated with close approach and rapid rotation, such as varying presentation of ellipsoidal bodies.

But throughout the whole range of periods covered by this curve, the effect of the discovery factor must not be overlooked. Very probably future discoveries of variables of this class, employing improved methods of search, will modify or perhaps transform conclusions drawn from the data now available; and this is especially true of deductions based upon magnitude range.

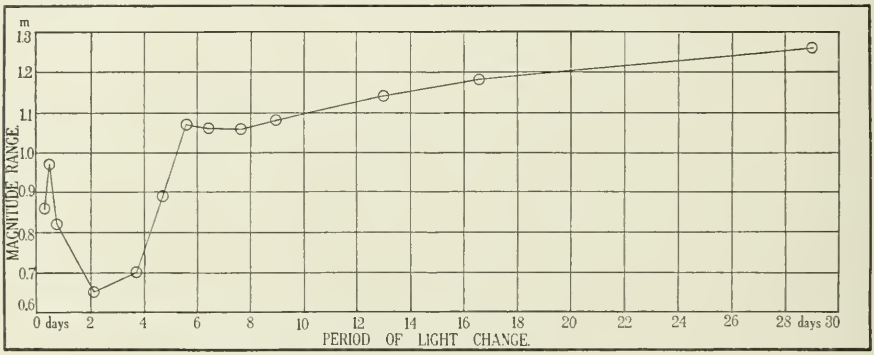


PLATE XVIII. THE VARIATION OF MAGNITUDE RANGE WITH PERIOD IN CEPHEID VARIABLES.

PERIOD AND VELOCITY RANGE.

In considering the element K, the velocity half-range, in relation to the period, attention should be directed at once to the possibility of predicting the average value of this element on the basis of the curve of Plate XVIII in combination with Ludendorff's relation,[2] $K = 23.7\,A$, where A denotes the magnitude range. But in the case of stars which have been observed spectroscopically this prediction is not verified, for the magnitude range of these stars differs greatly from the average values for all Cepheid stars, particularly if Pickering's photometric results are employed. This departure from the average curve may be connected with the greater relative brightness of these stars though there seems to be no clear evidence to support this view. More probably these apparent discrepancies are of a purely accidental type. For the *average* Cepheid variable, if K is directly proportional to the magnitude range on the average, as the facts for the brighter stars of this class seem to indicate, the variation of K with the period will follow that of the curve of Plate XVIII. As the period increases from two days the value of K increases rapidly at first and then more gradually, while the scale of the corresponding projected orbits depending on the product of K and P becomes relatively great. For periods less then two days K increases rapidly with decreasing periods down to about 0.5 days but there is no indication of further increase for periods less than this. Thus it would seem that for several stars with periods of a few hours the values of the semi-axes major are surprisingly small unless the inclination of the orbital planes be very small; and thus there is reason to think that the relation between velocity and light amplitude in Cepheid variables is not so simple as that expressed by the

[2] *Ast. Nach.*, Vol. 193, p. 301.

simple linear equation deduced by Ludendorff from stars with periods all greater than 3.7 days. It is possible, as suggested also by the distribution of these stars by periods, that those stars in Luizet's list with periods less than one day, form a group for which the causes of light variation differ from those which are present in the case of stars with periods greater than three days.

Whatever connection may be indicated between magnitude and velocity range in Cepheid variables it seems desirable to examine the available data for a direct relation between the velocity range and the period for these stars. If we plot values of K with periods as abscissae, a straight line with downward slope would seem to represent the plotted points as well as any curve. Thus the expression,

$$K = -0.93\,P + 24,$$

in which K and P are measured in kilometers and days respectively, is satisfied fairly well by the known values of these quantities. However, such an expression leads to impossible results for large values of P. Apparently the relation between P and K for these stars is better represented by the equation,

$$P = 2000/K^2$$

and the results in Table II are based on this expression. In this table, the difference between the observed velocity range, Ko, and that computed by the above formula, Kc, is exhibited for each star.

TABLE II.

STAR	P days	Kc km.	Ko km.	Ko—Kc km.	$(a \sin i)c$ km.	$(a \sin i)o$ km.	$(a \sin i)o$— $(a \sin i)c$ km.
RT Aurigae	3.73	23	17	—6	1,110,000	860,000	—250,000
SU Cygni	3.84	23	25	+2	1,180,000	1,350,000	+170,000
T Vulpeculae	4.44	21	18	—3	1,170,000	970,000	—200,000
δ Cephei	5.37	19	20	+1	1,330,000	1,370,000	+ 40,000
Y Sagittarii	5.77	19	19	±0	1,460,000	1,485,000	+ 25,000
X Sagittarii	7.01	17	15	—2	1,490,000	1,330,000	—160,000
U Aquilae	7.02	17	13±	—4	....	....	....
η Aquilae	7.18	17	20	+3	1,440,000	1,770,000	+330,000
W Sagittarii	7.60	16	19	+3	1,580,000	1,930,000	+350,000
S Sagittae	8.38	15	19	+4	1,670,000	2,000,000	+330,000
ζ Geminorum	10.15	14	13	—1	1,910,000	1,800,000	—110,000
Y Ophiuchi	17.12	11	8	—3	2,530,000	2,000,000	—530,000

If this relation be assumed between P and K, the expression connecting P and $a \sin i$ takes the form,

$$a^2 \sin^2 i = (6.15 \times 10^5)\ (1 - e^2)P.$$

Values of the projected semi-axis major computed from this formula are compared with the corresponding observed quantities in Table II for each star considered.

There seems to be some evidence in favor of the physical reality of these relations. But the data are few and so far as available results go, Polaris, X Cygni and l Carinae do not conform to the expression above. Possibly these relations are well enough defined to justify consideration when further data become available. They are advanced here only tentatively to present whatever evidence they may furnish.

MAXIMUM LIGHT AND MAXIMUM VELOCITY OF APPROACH IN CONNECTION WITH VELOCITY OF SYSTEM.

It is well known that there is a synchronism, more or less close, between maximum light and maximum velocity of approach in all Cepheid systems so far investigated. And convincing theories have been advanced which account for this condition on the hypothesis that there exists in each of these systems, a resisting medium which enhances the relative brightness of that side of the star which faces the direction of orbital motion. In this connection the suggestion arises that in the case of some systems (more probably in the case of a rapidly receding system) the primary is at no time moving toward the sun relatively to a resisting medium through which the system may be proceeding. In this event the periodic light variations of such a system may be dependent upon causes which are most effec-

tive on the side of the primary which is directed away from the earth. Possibly under these circumstances the correspondence between the velocity and light phases will not be so well marked on the average as in the case of a system approaching the observer.

To test this possibility, the data are again meager. In Table III, the Cepheid stars for which this datum is known are assembled in the order of increasing values of the velocity of recession of the system relative to Campbell's system of brighter stars. In the third column of the table, in parallel with these velocities, is given the corresponding quantity, time of maximum light, M_l, minus time of maximum velocity of approach, M_a, in terms of the corresponding light and velocity period. While the evidence is weak there is some indication of a tendency toward an increase in the absolute value of $M_l - M_a$ with increasing velocity of recession. The average values at the foot of the table indicate that this tendency is not associated with the elements, P, e, and the magnitude range.

TABLE III.

COMPARISON OF VELOCITY OF SYSTEMS WITH CORRESPONDING DIFFERENCES BETWEEN LIGHT AND VELOCITY EPOCHS IN CEPHEID VARIABLES.

STARS	VELOCITY OF SYSTEM	$M_l - M_a$	MAGN. RANGE	P DAYS	E
W Sagittarii	—19km.	—0.01P			
SU Cygni	—16	+0.05			
ζ Geminorum	— 7	—0.02			
X Sagittarii	— 4	—0.04			
δ Cephei	var.	+0.04			
η Aquilae	± 0	0.0			
S Sagittae	+ 4	—0.02			
Y Ophiuchi	+10	—0.10			
RT Aurigae	+12	+0.05			
T Vulpeculae	+14	+0.07			
Y Sagittarii	+16	+0.14			
Approaching Stars	—11	0.030P	0.75	7.1	0.29
Receding Stars	+11km.	0.076P	0.65	7.9	0.28

POSITION OF PERIASTRON.

In several papers in which the orbital elements of the Cepheid variable stars have been assembled, the fact has been evident that the values of the angular distance of periastron passage from receding node exhibit a preference for the first and second quadrants. From our knowledge of these stars, such a tendency is to be expected. For, if the well known tendency toward coincidence of the epochs of maximum light and maximum velocity of approach and also of the epochs of minimum light and minimum velocity of approach, in the Cepheid stars, studied spectroscopically, is to exist in combination with the well known tendency toward rapid increase and slow decrease of brightness in these stars, it is obvious that there must also obtain in these variables a tendency toward values of ω between 0° and 180°, or in other words, a tendency for the occurrence of periastron passage in the descending branch of the velocity curve. This tendency is brought out in Table IV in which the Cepheid stars are arranged in order of increasing values of the element ω. (SU Cygni is not included in Table IV because of an apparent error in the published value of ω for this star.)

TABLE IV. VALUES OF ANGULAR DISTANCE OF PERIASTRON FROM RECEDING NODE IN CEPHEID VARIABLES.

ζ Geminorum	—27°
Y Sagittarii	+ 32
η Aquilae	69
S Sagittae	70
W Sagittarii	70
δ Cephei	83
RT Aurigae	95
X Sagittarii	94
T Vulpeculae	111
Y Ophiuchi	+202

Not only do these values tend to group themselves in the first two quadrants but eight out of ten fall within limits of 40° of the value of 71°.

ζ Geminorum is a notable exception both to the tendency shown in Table IV and to the marked tendency toward asymmetry in the light curve. Y Ophiuchi presents an interesting exception in that its light curve is asymmetrical in conformity with the general tendency whereas its periastron passage occurs on the ascending branch of the velocity curve. Under these circumstances discrepancies are to be expected between the epochs of the light and velocity curves of this star. On the basis of the velocity curve computed by Miss

Udick[3] and the light curve of Pickering there is a close correspondence between the epochs of minimum light and maximum velocity of recession but a discrepancy of 1.7 days or one tenth of the period is found between the instants of maximum light and minimum velocity.

IRREGULARITIES IN THE VELOCITY CURVES.

The study of the velocity curves of a large number of spectroscopic binary stars has yielded results which support the conclusion that real departures from a form corresponding to elliptic motion in these curves, not due to blending of lines, seldom attain to an appreciable magnitude, even in the case of very close pairs. However in the case of the Cepheid variables which have been studied with the spectrograph there are three conditions which are thought to obtain in the average case and which in *some* cases would seem to be competent to produce recognizable distortions in the velocity curves of these stars. Thus, there is evidence to show that the principal component, whose spectrum is observed, is of many times the volume of our sun. Possibly one hemisphere of this primary is about twice as bright on the average as the other. Probably this star rotates in a period not far different from 7.5 days, the orbital period of the average pair. If these three conditions are suitably combined in any one case it would seem probable that irregularities in the velocity curve of such a star might be observed.

The evidence pointing toward the probability of the existence of these three conditions in Cepheid stars has been discussed more or less by several investigators. On the basis of the magnitudes and observed proper motions of six Cepheid variables Ludendorff has pointed out the strong probability that the average absolute brightness of these stars even at minimum light is considerably greater than that of our sun. Making only the most reasonable assumptions he shows that these stars on the average are probably about fifty times brighter at light minimum than is the sun.[4] Since the spectrum of these stars is invariably of solar type, it seems probable that the surface brightness of these bodies is not far different from that of our sun. It therefore may be considered as probable that the surface of the average Cepheid star of this group is considerably more extensive than the sun's surface.

Suggested conclusions with reference to an effective difference between the apparent brightnesses of opposite hemispheres of a Cepheid star are based upon studies of the light and velocity variations. As stated above, a promising theory, advanced to account for the light variation of Cepheid variables, is based on the assumption that the hemisphere of the primary which faces the direction of orbital motion is rendered more luminous relatively to the following half of the star by the action of a resisting medium. There seems to be much to recommend this theory as first proposed by the writer in connection with studies of W Sagittarii. Whether the assumed resisting medium produces a relative difference in the brightness of the advancing and following faces of a moving star by meteoric bombardment, as suggested by Loud, or by displacement of the atmosphere, as suggested by Duncan, or whether *both* effects are present, it would seem that a variation of the kind observed in Cepheid variables might result.

If it be the brighter half of the primary which is exposed to the observer's view at the time of maximum light and maximum velocity of approach, and if it be the fainter half which is seen at the time of minimum light and of minimum velocity of approach, a basis is furnished for the estimation of the relative brightness of these two unequally luminous regions of the star's surface, since the corresponding range in apparent brightness is known. Now the range of magnitude for the average Cepheid variable in Table III is about 0.7; and if this be considered a measure of the difference in effective brightness of the brighter and darker hemispheres of each star on the average, it would seem that, in the minimum, the brighter half of the primary's surface must emit about twice as much light as the fainter hemisphere.

As to the probable value of the period of rotation of a component of a Cepheid pair there would

[3] *Publications of the Allegheny Observatory*, Vol. II, p. 151.

[4] See also Russell's paper, *Science*, Vol. 37, p. 652.

seem to be some room for speculation, particularly in view of the high average eccentricity observed in these systems. Although the mass of the secondary is probably relatively small, it will be considered that the operation of tidal friction in these systems would tend to place or hold the rotational and orbital periods in coincidence or commensurability, opposing the tendency toward rotational acceleration due to contraction. At least it seems probable that the rotational and orbital periods will be of the same order of magnitude in any Cepheid star.

If, in application of the above conclusions, we make the apparently conservative assumption that the area of the surface of the primary of the average Cepheid variable star is four times that of our sun, the period of rotation being seven days, it follows that the rotational velocity of an equatorial point of such a star will take the large value of fourteen kilometers per second. Accordingly, if the distribution of luminosity over the surface of such a star be such as has been assumed above as probable, it would seem that cases with velocity curves showing irregularities of appreciable magnitude might occur among Cepheid variables.

However, it must be kept in mind that the ease of detection of a secondary curve superposed upon a velocity curve corresponding to orbital motion in a closed conic section depends not only on the magnitude of the irregularity but also upon its period and position with reference to the primary and upon the form of the two curves combined.[5] Thus, if we superpose a curve corresponding to circular motion upon another of the same period, the result is a circular velocity curve whatever the relative phases of the original curves may be. Consider an elliptic velocity curve corresponding to the orbital elements which we may consider normal to the average Cepheid variable: $e = 0.30$, $\omega = 70°$, $K = 17$ km. If we superpose upon this a sine curve of the same period, representing the velocity curve due to the rotation of a star with unequally bright hemispheres and expressed by equation,

$$V = -6 \sin (M + \omega) \text{ kilometers,}$$

(the simplest assumption and perhaps a reasonable one so far as the amplitude is concerned) there results a curve which is satisfied throughout its length within a fraction of a kilometer by the elements, $e = 0.28$, $\omega = 110°.6$, and $K = 18.0$ km. If, then, the secondary curve produced by rotation in any system is a simple sine curve, with a period equal to the orbital period, its presence will not be recognized under these circumstances even though it may alter quite appreciably the elements derived in the usual manner from the velocity curve.

However it is probable that no one will maintain that the rotational curves of a Cepheid variable under the conditions here supposed would usually be simple regular figures like a sine curve with the period identical with the orbital period. A consideration of the librations and varying orbital velocity in the Cepheid systems of marked eccentricity would render this view untenable. Accordingly, if the conditions assumed above are present in the average Cepheid system it would seem that some cases of irregularity in their velocity curves might be found.

There are ten Cepheid variables including Polaris of which the velocity curves are fairly well determined. Of these, two (those of ζ Geminorum and W Sagittarii) are known to be irregular; one (that of RT Aurigae) shows strong evidence of irregularity: and two (those of η Aquilae and Y Ophiuchi) have been suspected of irregularity. In addition, the velocity curve of S Sagittae has given evidence of departure from elliptic form. Probably this proportion of curves, irregular or suspected of irregularity, is such as we might expect in view of the points discussed above.

Although the detection of a secondary sine curve of the same period as the principal curve may not be possible, it will nevertheless be interesting to examine the irregular velocity curves of two of these stars, ζ Geminorum and W Sagittarii, in an avowedly preliminary way, to determine the possible character of the secondary

[5] See Russell's paper *Astronomical Journal*, Vol XV, p. 252.

curve, *considered as due to rotation,* under various assumptions as to its period and the elements of the principal curve, and to consider the secondary curves so found in connection with the rotation theory here proposed.

The irregularity of the velocity curve of ζ Geminorum was established by Campbell, whose excellent observations, extending from 1898, November 11, to 1900, February 11, indicated that this irregularity was not a rapidly changing phenomenon. He considered the period of the superposed curve to be one-third that of the principal on the average, but on that basis did not succeed in determining a secondary curve of closely similar amplitude, form and period throughout the three complete excursions comprised in one period of the principal curve. The observations are plotted in the lower figure of Plate XIX.

The irregularity of the velocity curve of W Sagittarii was discovered by the writer. The observations, which were made for the most part in one year, were not sufficient to determine the details of the curve with great accuracy, but the general form, including the irregularity, was well established. The secondary or superposed curve was considered to be a sine curve with an amplitude of 4.2 km. at the crest and 5.5 km. at the trough with a period one-half that of the primary curve. Subsequently a striking resemblance was noted by the writer between the velocity curve of this star and the photometric light curves which had then been published, as determined by E. C. Pickering a few years before.

At first sight there seems to be little resemblance between the velocity curves of ζ Geminorum and W Sagittarii. So far as the writer knows, none has been pointed out. But if either curve be reversed, as the reader may do mentally in connection with Plate XIX, the form of the two curves becomes strikingly similar. Indeed the conclusion is at once suggested that a similar though reversible process of periodic change is revealed in each system. But, though this may be the case, further examination has not indicated that these curves illustrate direct and reversed aspects of exactly the same cyclical change.

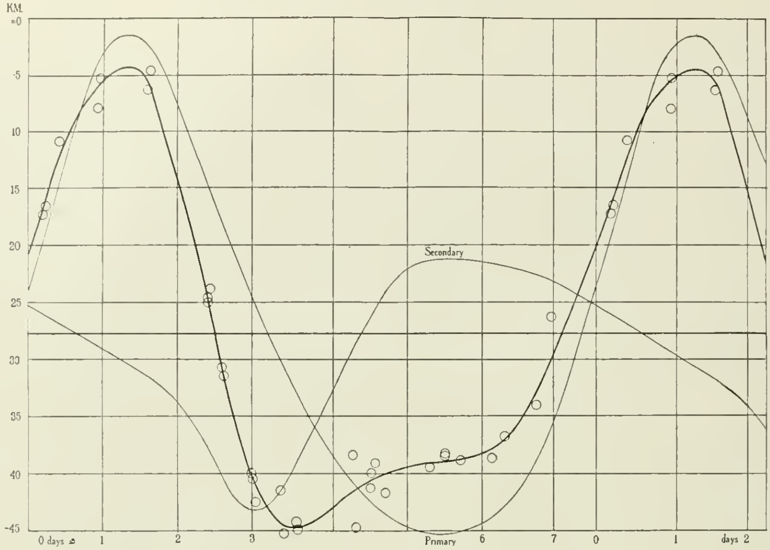
EXPERIMENTAL CURVES.

Considering first the case of ζ Geminorum (the heavy line of the lower figure of Plate XIX), on the assumption that the orbital and secondary periods are closely identical, a secondary oscillation, one of the many possible, is at once suggested by the form of the velocity curve. But in order to test the possible application of a rotational theory, the selection of the principal curve may be influenced especially by three considerations: that the secondary oscillation should be regular, that the cross points of principal and secondary curves should be roughly one-half period apart, and that the displacement of the velocity curve with reference to the orbital curve should be negative on the descending branch and positive on the ascending branch of the latter curve. One set of elements is given in Table V.

TABLE V.—ELEMENTS OF THE VELOCITY CURVE OF ζ GEMINORUM.

	PRIMARY CURVE	SECONDARY CURVE
P	10.154 days	10.154 days
ω	295.°7	———
e	0.11	———
T	8.42 days	———
A	+26.0 km.	+8.5±km.
B	−10.0 km.	—6.5±km.
V_s	+7.1 km.	———

A glance at the curve of short dashes in the lower figure of Plate XIX will disclose the character of the selected secondary oscillation. It will be seen that it is little if any more closely like a circular velocity curve than is Campbell's third-period oscillation. Further the deviations of this secondary from a circular velocity curve are about as great at some points as the deviation of the velocity curve from a mean elliptical curve. Evidently this empirical analysis of the velocity curve does not lead to a simple secondary oscillation and from that point of view does not simplify the problem. It does suggest the presence in the system of a large effect due to rotation which, if established, might explain the irregularities so far unaccounted for. But the objection remains that a large irregularity is assumed in order to explain one apparently much



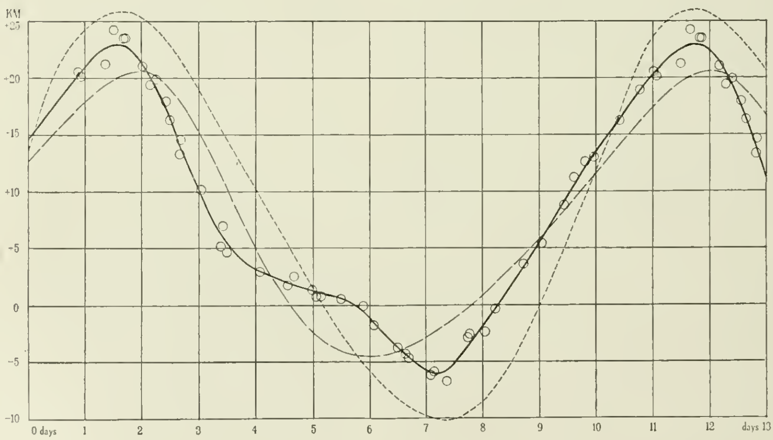


PLATE XIX.

UPPER FIGURE. SUGGESTED ORBITAL AND ROTATIONAL CURVES OF W SAGITTARII. (OBSERVATIONS BY CURTISS.)

LOWER FIGURE. EXPERIMENTAL ORBITAL AND ROTATIONAL CURVES OF ZETA GEMINORUM. (OBSERVATIONS BY CAMPBELL.)

smaller and by some this will be considered unfavorable to the reality of the curves drawn. So far as this combination of curves goes, as well as other combinations which have been considered by the writer, there seems to be nothing pointing definitely to the action of rotation in a whole period as producing the irregularities in the velocity curve of ζ Geminorum.

Though deviations of the secondary oscillation from a sine curve are not to be considered fatal to a rotational hypothesis there are certain conditions which such an oscillation might be supposed to satisfy. If the primary curve is to be considered as corresponding to the true elliptical motion of the primary star, the excursions of the actual velocity curve with reference to this primary being attributed to the rotation of this body, assumed to be unequally bright, in a period equal to the orbital period, the cross points of the two curves should represent instants when the brighter hemisphere is presented to or away from the observer. Apparently, on this basis, as is evident from a consideration of the relative positions of the orbital and rotational curves, the cross-point at phase, 2.9 days, should correspond to the instant of presentation of the bright area of the star's surface to the observer; and the cross-point at 8.2 days, to the instant of presentation of the darker area. Apparently these velocity phases ought to correspond to the epochs of maximum and minimum light. But the first precedes the light maximum by about one-fifth of the orbital period; and the second, the light minimum by a like interval. An explanation for this discrepancy is suggested if we note that the first cross point occurs at apastron and the second at periastron. Though the brighter area of the star may be presented to the observer at the instant corresponding to the first cross point, the brightening of the star's surface due to greater orbital velocity after apastron passage may, for a time, overcome the dimming due to the turning away of the brighter area by rotation. Similar considerations may be advanced to account for the discrepancy in connection with the second cross point.

It might also be expected that the cross points of the principal and secondary curves would synchronize more closely with the epochs of orbital maximum and minimum of velocity. Only part of this discrepancy is explained as the result of simple librations. To account for the rest we may make various assumptions: e. g., that part of the brightening effect of the resisting medium is of a semi-permanent nature, and that the period of rotation is a very little shorter than the orbital period.

Considering the velocity curves of W Sagittarii on the same basis as above, the rotational and orbital periods being assumed closely identical, primary and secondary curves have been determined as represented by the elements in Table VI. In this case there seems to be no connection between the curves derived and the rotation theory proposed above unless the direction of rotation be opposite to that of orbital revolution; and such a condition appears so improbable that the corresponding curves have not been shown.

TABLE VI.—ELEMENTS OF W SAGITTARII.

	PRIMARY CURVE	SECONDARY CURVE
P	7.595 days	7.595 days
e	0.26	———
ω	72.°7	———
T	1.15 days	———
A	+ 1.0 km.	+10 km.
B	—53.6 km.	—10 km.
V_0	—28.4 km.	

But other interpretations of the velocity curve of W Sagittarii are possible if we adopt a secondary oscillation, differing considerably from a sine curve both as to form and equality of positive and negative amplitude, but showing no marked irregularities, and conforming well to certain requirements of a rotation theory. The elements of one set of curves are given in Table VII, and the curves themselves are shown in the upper figure of Plate XIX.

TABLE VII.—SECOND ELEMENTS OF W SAGITTARII.

	PRIMARY CURVE	SECONDARY CURVE
P	7.595 days	7.595 days
e	0.21	———
ω	333.°0	
T	4.71 days	
A	— 1 2 km.	+ 6.5 km.
B	—45.7 km.	—15.5 km.
V_0	—27.8 km.	

In selecting this primary curve three considerations have been kept particularly in view; that there should be one maximum and one minimum in a complete oscillation of the secondary curve, that the cross points of the primary and secondary curves should be very nearly one half-period apart, and that the displacement of the velocity curve with reference to the orbital curve should be negative on the descending branch and positive on the ascending branch of the latter curve —all in accordance with the simplest application of a rotation theory. The amplitude and form of the secondary oscillation (shown clearly in the upper figure of Plate XIX) result from the application of these conditions with an added preference for smaller amplitudes.

In this case it will be noted that the cross points corresponding to presentment of the darker area to the earth precedes the light minimum by one-tenth of the period; and the cross point corresponding to presentment of the brighter area to the observer follows the light maximum by a slightly greater interval. But periastron occurs immediately ($0.035P$) after the first cross point; and apastron shortly ($0.040P$) after the second. These last facts suggest that the increasing faintness of the following side of the star in the neighborhood of periastron passage modifies the rotational effect and retards the occurrence of minimum light, and that the decreasing brightness of the preceding face as the velocity approaches its minimum at apastron leads to the occurrence of maximum light shortly before the brighter area is most nearly presented to the observer.

The greater amplitude of the minimum of the secondary curve as compared with that of the maximum may also be explained through a consideration of the time of occurrence of these phases with reference to periastron and apastron. Thus the great amplitude of the minimum of the secondary or rotational curve following periastron may he due to the greater difference in brightness of the brighter and darker areas of the star after its relatively rapid motion in this section of the orbit; and the smaller amplitude at maximum of the rotational curve following apastron passage may be due to the smaller difference between the brighter and darker areas of the star after its slower motion through this section of the orbit.

But the assumed rotational curve in this instance is of peculiar interest because its form may be considered to point to an unsymmetrical brightening of the rotating star. As Loud has pointed out, if the resisting medium diminish the period of revolution sufficiently, the period of rotation may very slightly exceed that of revolution and the point of maximum brightness near the advancing front may move slowly around the star's equator, leaving a trail of diminishing brightness. Then, as the star rotates, bringing into view first the region of greatest brightness and, in their turn, those of declining brightness, there ensues the rapid rise and slow decline of apparent total light characteristic of Cepheid stars. At the same time, a rotational curve somewhat similar in form (and possibly also in amplitude) to that shown here would result; and the effect upon the *observed* velocity curve would be evident in a strong depression in the descending branch, tending to increase the eccentricity, in general, and tending to throw the apparent periastron point into the first and second quadrants. The orbital curve of W. Sagittarii, adopting a secondary of this type, tends toward a circular form.

Under this hypothesis, it seems not impossible that the orbits of the Cepheid stars, studied with the spectrograph, may be considered to be more nearly circular. Further, on this hypothesis, the proportion of light and velocity curves with recognizable irregularities might be such as actually found. And in some cases, as possibly in ζ Geminorum, a close synchronism of rotation and orbital motion may accompany roughly symmetrical (though perhaps irregular) brightening, leading to nearly symmetrical (though perhaps irregular) light and velocity curves. No other hypothesis so far proposed seems to account for so many Cepheid characteristics as that of Loud. But for a typical case with ω in the neighborhood of seventy degrees, if this type of secondary be assumed as due to rotation, the additional assumption, that the brighter area of the star is directed roughly toward the center of the nearly circular orbit, would seem to be suggested.

Up to this point, in considering the systems of ζ Geminorum and W Sagittarii, it has been assumed that the angular rates of rotation and orbital revolution are closely similar and that the direction of each is the same. As to the close identity of the direction of orbital motion and rotation there seems little room for question though the axis of rotation may not be accurately perpendicular to the orbital plane. Further, in case of circular orbital motion there seems to be justification for the assumption, frequently made, that orbital and rotational periods are equal. However, in the consideration of close binary systems of high orbital eccentricity, if this identity be adopted, the resulting librations become so great that serious question arises as to the advisability of the assumption. If we consider the average Cepheid variable of Table III, we find the eccentricity to be about 0.29. In such a system, if the identity of the orbital and rotation periods be assumed, the excess of the orbital revolution over the angular motion of rotation during periastron passage from latus rectum to latus rectum again is 65°—more than one-third of the change in true anomaly. During the corresponding apastron passage, the extent of this libration is nearly the same; but, as the writer has pointed out, the tidal force varies in the ratio of one to eight between the apastron and periastron points, and the tidal forces are far more effective in the neighborhood of periastron. Thus the question arises: In the case of close binary systems of high eccentricity, will the greater tidal action in the section of the orbit near periastron induce, as the result of tidal friction, an angular velocity of rotation which will follow closely the angular velocity in this part of the orbit?

In a system with an orbital eccentricity of 0.35, if the period of rotation be one-half the orbital period, the same area of each star will be presented to the companion throughout an arc of 73° at periastron with a libration not exceeding 2½°, and throughout an arc of 120° with a libration of 20°. Under the assumption of identical orbital and rotational periods the corresponding librations would be 34° and 41° of stellar longitude. Under these circumstances is it possible that a period of rotation of one-half the orbital period will best satisfy the conditions in the system? Possibly the answer to these highly interesting questions will sometime be found through the study of Cepheid variables.

If the half-period rotation is to account for the irregularities in the velocity curve of such a star as W Sagittarii it seems necessary to assume that there is between two hemispheres of the rotating star a difference of effective brightness semi-permanent in character and not immediately dependent on the action of a resisting medium at any instant if such be assumed. That such a semi-permanent effect may be present in these Cepheid stars seems not unreasonable in view of the relatively higher orbital velocities near periastron and in view of the presentation in orbits of certain eccentricities, of the same face of the star very closely in the direction of orbital motion during ninety degrees of anomalistic motion near periastron. Possibly then the relative brightness differences of the preceding and following faces of the star, set up during motion about periastron, remains a semipermanent feature of the star's surface. If this effect were present, a secondary velocity curve due to a half-period rotation might manifest itself—greatly modified perhaps by more rapid surface changes immediately attending orbital motion. Possibly the components in the velocity curve due to the rapid changes of surface brightness combined with rotation would follow a sine curve closely with a period identical with that of orbital revolution and might not be detected even if relatively great. But the effect of a half-period rotation combined with a considerable permanent difference of relative brightness between two hemispheres might be readily observed.

Already the velocity curve of W Sagittarii has been studied by the writer on the assumption that the period of the secondary curve is half the orbital period. The elements derived are reproduced in Table VIII. The corresponding curve has been published in No. 62 of the *Lick Observatory Bulletins* and in the *Astrophysical Journal*, Volume 20, p. 149. The secondary curve seems to follow a sine curve closely, and the eccentricity of the corresponding orbit of the system is such that the assumed period of rotation seems not unreasonable.

TABLE VIII.—ELEMENTS OF W SAGITTARII.

	PRINCIPAL CURVE	SECONDARY CURVE
P	7.595 days	3.8
ω	70.0 degrees	———
e	0.320	0.0
T	6.20 days	
A	+21.6 km.	+4.2 km.
B	—17.4 km.	—5.5 km.
V_0	—28.6 km.	

TABLE IX.—ELEMENTS OF ζ GEMINORUM.

	PRINCIPAL CURVE	SECONDARY CURVE
P	10.154 days	5.08 days
ω	58.9 degrees	———
e	0.18	———
T	1.10 days	———
Max. Vel.	+21.5 km.	+4.5 ± km.
Min. Vel.	— 5.5 km.	—4.5 ± km.
V_0	+ 6.8 km.	———

The position of the secondary curve considered in connection with the rotation theory advanced above indicates that the brighter face of the star is most nearly directed to the earth at maximum light. Immediately thereafter, as the rotation turns the brighter face away, a secondary light minimum has been observed, according to Pickering. This is followed by a secondary maximum, 3.8 days after the principal maximum, at which phase a cross point of the velocity curves occurs and the more permanently brighter area of the rotating star is again presented to the observer according to the rotation theory. Near principal light minimum the brighter area is again turned away from the observer at the fourth cross point of the secondary curve. Thus some relation between the light curve and the above interpretation of the velocity curve is indicated. The double amplitude of the secondary light oscillation is about 0.24 magnitudes and that of the principal light variation, 0.6 magnitudes.

The velocity curve of ζ Geminorum has also been studied on the assumption that the rotation period is half the orbital period and that a permanent difference of brightness exists between two opposite hemispheres of the principal star. The resulting elements are given in Table IX. In this case the form of the secondary curve is irregular. Also the same face of the visible star is presented to the observer at maximum light and at minimum light on the rotation theory. There seems little to recommend these curves as representing real conditions in this system.

If the rotation theory here outlined be assumed, the more probable additional assumption seems to be that the orbital and rotational periods of ζ Geminorum are closely identical. But on this assumption, there are certain discrepancies to be explained and the resulting secondary oscillation curve differs from a sine curve by quantities about as great as the semi-amplitude of Campbell's third-period secondary. Whereas a rotational effect is probably present, it is not definitely indicated so far as these investigations go. In the case of W Sagittarii there is evidence of a connection of rotational effects with the irregularities observed both in the light and velocity curves.

SUMMARY.

1. Studies of the distribution by periods of the stars of Luizet's list of Cepheid variables indicates that these stars may be divided tentatively into two classes: one with a preference for periods of four to eight days, but possibly including variables with periods up to 100 days or more; the other with periods less than two days.

2. Studies of the relation between average magnitude range and period indicate that these two quantities are connected by a complex relation undoubtedly involving many factors. A well determined curve connecting these two elements is shown in Plate XVIII.

3. On the basis of Ludendorff's equation between velocity and magnitude range in Cepheid variables, a relation between the light period and the average velocity range ought to follow in

accordance with the curve of Plate XVIII. The reality of such a relation is questioned. The relation, $P = 2000\ K^2$, is tentatively proposed.

4. Some indication is found of an increase, with increasing systemic velocity, in the observed discrepancy between the times of occurrence of light maxima and velocity minima in Cepheid systems. This relation is possibly in harmony with the assumption of a resisting medium in the system.

5. In accordance with the known light and velocity relations in Cepheid systems, it should be expected, as the known results show, that a preference for the first two quadrants should be exhibited in the values of the angular distance of periastron from the node.

6. On some grounds it seems probable that the surface area, surface luminosity and axial rotation of some Cepheid variables is such that rotational effects in their velocity curves are to be expected. If the superposed curve due to rotation is of small amplitude or differs little from a sine curve of period equal to the orbital period, its presence may not be detected though the elements of the system as derived from the velocity curve will be more or less affected. If the secondary is irregular or different in period from the primary, its presence will be more clearly revealed. If the orbital and secondary periods are alike, the form of these curves will in general be indeterminable. But, keeping the simplest requirements of the rotational effect in mind, principal curves may be selected and the resulting secondary oscillation may be examined.

Preliminary studies of the velocity curve of ζ Geminorum indicate that, while velocity displacements of considerable magnitude may be caused by rotation in this star, no simple application of a rotation theory has accounted definitely for the irregularities observed. The irregularities in the velocity curve of W Sagittarii are perhaps more in harmony with the application of a rotation theory in connection with a theory of unsymmetrical brightening, or in connection with the assumption that the rotation period is one-half the orbital period if such be possible.

CONCLUSION.

It will be noted that appeal has been frequently made in this discussion to the theory that a resisting medium is present in any Cepheid system, which enhances the relative brightness of that side of the visible component which faces the direction of orbital motion. This theory accounts for a number of established facts in connection with these systems.

It is especially interesting to consider the effects that the presence of such a medium might have upon the orbital elements of such a system. If of sufficient density, it is quite possible that its action would reverse, under some circumstances, or balance, under others, the tendency toward a lengthening of the period of revolution resulting from tidal friction and would thus maintain or produce an exceptionally small value of the orbital period in these systems even though they be relatively old. In this way the occurrence of solar type binaries of relatively short period, which is characteristic of many Cepheid variables may be accounted for. On the other hand the well known perturbation in the eccentricity due to the action of a resisting medium on a body moving in an eccentric orbit, might be expected to have tended toward smaller values of the eccentricities in these systems. That the eccentricities so far *observed* in Cepheid systems average large may indicate that the conditions (e. g., tidal friction) favorable to increasing eccentricity, which have operated in the average binary system old enough to have assumed the solar type spectrum, may also have predominated here in their influence upon departure from orbital circularity.

At the same time, it seems quite possible that the *true* orbital curves of the Cepheid stars are, as a rule, nearly circular. The eccentricity as well as the irregularities of the *observed* velocity curves may be due to the superposition of unsymmetrical rotational displacements, explicable on the basis of some theory similar to that of Professor F. H. Loud, discussed briefly above.

August 1, 1913.

STUDIES OF THE SPECTRA OF DELTA AND EPSILON ORIONIS

By RALPH H. CURTISS

The recent discovery by Stebbins of light variations due to eclipses in the system of δ Orionis has made desirable a reinvestigation of the orbital elements of this star in order that recently observed velocities may supplement the light measures in the determination of the constants of this system. In addition, spectroscopic studies of this star are of especial value in themselves at this time because of the fact that this is one of a very few short period binaries of which reliable elements are determinable, dating back eleven years, making possible the accumulation of some evidence with reference to the variability of the orbits of close systems. Also in connection with this star, further studies of the sharp apparently fixed K line of Calcium, discovered by Hartmann, are desirable, as well as an inspection of the visual region of the spectrum.

The spectroscopic study of ϵ Orionis was undertaken at this time chiefly in order to throw light upon the question of the availability of this star as a reliable comparison source, in which capacity it had been used by Stebbins in all his observations of δ Orionis. In this connection it is important to know the period and extent of the velocity variations. Considerable interest also attaches to the study of the velocities obtained from the H and K lines in the spectrum of this object, and to the inspection of the visual region of this spectrum.

These considerations have led to the inclusion of these two stars in our rather limited observing list of miscellaneous objects apart from our regular programs of spectroscopic work.

δ ORIONIS.

The Total Light.

The visual magnitude of δ Orionis ($\alpha = 5$h 27m, $\delta = -0^\circ\ 22'$), as given in the Revised Harvard Photometry, is 2.48; and in view of the character of the spectrum the photographic magnitude may be taken as 0.3 of a magnitude brighter. A variation of the visual brightness of this star (between the magnitude limits, 2.2 and 2.7, according to Schönfeld) was thought by J. Herschel to have been detected by him, but subsequent observations by various observers have led to contradictory results. Auwers considered that he had established in 1854, and followed until 1858, a regular variation of the light with a period of 16.08 days, a quantity nearly equal to three times the orbital period. Later observers, including Chandler and Sawyer, failed to confirm Auwers' results and attributed the variations observed by him to difficulties due to the low altitude of this star. δ Orionis is not included in recent catalogs of variable stars.

Professor J. Stebbins detected and studied eclipse variations, with double minima, in the light of δ Orionis and announced his results before the Astronomical and Astrophysical Society of America in 1911. The photometric observations and light curve, which he has kindly furnished me, indicate that the magnitude range of the light variation as measured with the selenium cell is 0.10 magn., that the phases of the light minima synchronize closely with those of orbital conjunction, and that the light variation is probably continuous like that of a β Lyrae variable. A striking but by no means unprecedented feature of this light curve is found in a pronounced asymmetry of the depressions at the minima. It was this feature which led more particularly to the spectral studies at the Detroit Observatory, which are described in this paper.

THE SPECTRUM.

In the Harvard Annals the spectrum of δ Orionis as well as that of ϵ Orionis is assigned to Class B of which the latter star is chosen as a typical object. Much detail with reference to the measurable lines in these spectra will be found in Table I, the first two columns of which contain the wave-lengths determined by Hartmann for δ Orionis as well as the lines used by him in velocity determinations. The next four

columns contain the wave-lengths, relative intensities, number of measures and probable errors of the lines in the same star as studied by the writer; columns 7 to 10, similar data by the writer for ϵ Orionis; and the last two columns of the table, the wave-lengths adopted by the writer in this paper together with partial identification and assignment of authority.

Comparing columns 1 and 5 it is evident that the character of the spectra measured by Hartmann and the writer was essentially the same and that there had been no important changes in the photographic spectrum in eleven years. Differences in opinion as to the availability of a few difficult lines for velocity work are accountable on the basis of instrumental differences and very slight differences of judgment. If there has been any real change in this spectrum since the epoch of Hartmann's spectrograms it may be found in λ 4481 of magnesium which Hartmann employed in his velocity determinations and which the writer found to be an extremely difficult line and one not available for velocity work.

A comparison of columns 3 and 4 with columns 7 and 8 of Table I brings out interesting differences between the lines of the spectrum of δ Orionis and those of the typical Class B spectrum of ϵ Orionis. The presence of a greater number of measurable lines in column 7 is due partly to the superior definition of all lines in the spectrum of ϵ Orionis but also to real differences of intensity between lines found in this star and their counterparts in δ Orionis. Consulting the intensities, in columns 4 and 8, which are the means of the estimates made at each measurement of each line, it will be seen that there is a striking resemblance between the absolute intensities in these two stars of the lines of helium and the Huggins series of hydrogen, while the two representatives of the Pickering series and Fowler's principal series line at λ 4686 are certainly stronger in δ Orionis. Of the three strong lines near Hδ, λ 4089 is of equal intensity in both spectra while the other two are considerably stronger in ϵ Orionis. Metallic lines, such as λ 4481 of magnesium, λ 4553, λ 4568 and λ 4575 of silicon, are decidedly stronger and better defined in ϵ Orionis. Apparently, according to present ideas, the spectrum of δ Orionis corresponds to an earlier stage of evolution than that of ϵ Orionis.

The wave-lengths in this table with their probable errors require very little discussion at this time. It is expected that they will be of value in connection with studies of variation of wave-length in stellar spectra from type to type. Possibly the most interesting difference between the adopted wave-length and that found from the measures is met with in the case of Hδ. The adopted value, λ 4101.92, was derived from measures of spectra of stars somewhat more advanced in type than is δ Orionis. In the spectra of these stars a measurable nucleus is often found in the Hδ line, a feature not found in this line in δ Orionis. In ϵ Orionis, where this line is much sharper than in δ, the wave-length of Hδ conforms more closely to the value for stars of later type.

The exceedingly diffuse appearance of the absorption lines in δ Orionis has been commented on by Hartmann. He says, "On account of the slight intensity of the lines, all defects of the film are very disturbing and, in consequence of the irregular distribution of the silver grains, the lines often appear crooked and unsymmetrical, sometimes indeed double. I have convinced myself by a special investigation that the indications of duplicity and unsymmetrical broadening cannot be caused by lines belonging to a second component of the stellar system; but I do not hold it to be impossible that the form of the lines is subject to small real changes, perhaps in consequence of violent motions in the gaseous envelope of this star."

TABLE I. WAVE-LENGTHS OF LINES IN THE SPECTRA OF δ AND ϵ ORIONIS.

δ Orionis						ϵ Orionis					
Hartmann		Curtiss				Curtiss					
Wave-lgth.	No. meas.	Wave-length	Int.	No. meas.	P. E.	Wave-length	Int.	No. meas.	P. E.	Adopted wave-length	Authority and identification
(1) Å	(2)	(3) Å	(4)	(5)	(6) Å	(7) Å	(8)	(9)	(10) Å	(11) Å	(12)
Assumed	..	....	....	..	.....	3889.13	22.–	3	±0.077	....	$H\zeta$.
3933.68	7	....	3.0	43	.....	....	4.0	27	.....	3933.825	K. Rowland.
....	..	....	....	..	.....	3964.70	4.2	7	0.044	....	Helium.
....	..	....	2.6	21	.....	....	3.5	12	.....	3968.625	H. Rowland.
Assumed	..	3970.30	17.2	21	±0.037	3970.22	16.1	14	0.029	3970.18	$H\epsilon$. Rowland.
....	..	....	....	..	.....	4009.50	3.7	6	0.025	4009.42	Runge and Paschen.
Assumed	..	4026.33	17.8	66	0.015	4026.34	13.7	30	0.012	4026.37	Runge and Paschen.
4069.49	3	....	....	..	.....	....	....	..	.....	....	....
....	..	....	....	..	.....	4076.02	4.3	12	0.034	....	Oxygen.
Assumed	..	4089.19	15.4	41	0.032	4089.08	14.5	30	0.011	4089.00	Si. Lunt.
4097.49	5	....	....	..	.....	4097.56	6.8	22	0.028	4097.47	N or Si.
Assumed	..	4102.11	25.9	68	0.018	4102.01	25.5	22	0.018	4101.92	See text. $H\delta$.
4116.28	11	4116.31	8.4	47	0.019	4116.31	11.0	30	0.009	4116.30	Lunt and Hartmann.
....	..	4121.01	5.1	8	0.095	4120.88	5.2	10	0.048	4121.02	Runge and Paschen.
4143.94	2	4144.07	5.8	6	0.042	4143.87	5.8	21	0.021	4143.92	Runge and Paschen.
4200.42	2	4200.17	4.8	5	0.058	4200.28	3.4	4	0.084	....	$H\delta'$.
....	..	....	....	..	.....	4253.81	3.1	14	0.050	....	Sulphur
....	..	....	....	..	.....	4267.42	3.5	4	0.093	4267.15	C. Eder and Valenta.
....	..	....	....	..	.....	4317.27	2.6	5	0.11	....	Oxygen.
....	..	....	....	..	.....	4319.76	2.5	6	0.091	....	Oxygen.
Assumed	..	4340.56	16.8	72	0.012	4340.65	18.9	31	0.020	4340.63	$H\gamma$. Rowland.
....	..	....	....	..	.....	4345.78	2.–	3	0.18	....	Oxygen.
....	..	....	....	..	.....	4349.85	3.5	11	0.071	....	Oxygen.
Assumed	..	4388.06	7.0	51	0.028	4388.04	6.7	29	0.023	4388.10	Runge and Paschen.
Assumed	..	4471.61	11.8	72	0.015	4471.68	10.7	31	0.013	4471.68	Runge and Paschen.
Assumed	..	....	....	..	.....	4481.38	2.3	6	0.052	4481.40	Mg. Frost.
4541.78	2	4541.72	5.3	14	0.040	4542.02	3.2	6	0.090	....	$H\gamma'$.
....	..	....	....	..	.....	4552.76	5.2	25	0.025	4552.76	Si. Albrecht.
....	..	....	....	..	.....	4567.94	3.8	21	0.038	4567.97	Si. Albrecht.
....	..	....	....	..	.....	4574.74	2.6	7	0.036	4574.92	Si. Albrecht.
....	..	....	....	..	.....	4638.48	2.2	6	0.15	....	Blend.
....	..	....	....	..	.....	4641.87	6.8	12	0.11	....	Oxygen.
....	..	4647.90	7.0	11	0.12	4647.74	9.9	19	0.042	....	First Component.
4649.68	16	4649.56	26.1	61	0.038	4649.42	28.3	30	0.015	....	Blend.
....	..	4650.93	9.2	11	0.10	4650.63	12.1	19	0.040	....	Second Component.
....	..	....	....	..	.....	4661.72	2.8	5	0.15	....	Oxygen.
4686.20	10	4686.14	7.4	41	0.041	4686.01	4.6	10	0.075	4686.00	Hydrogen.
....	..	4713.36	7.0	31	0.039	4713.32	6.8	26	0.031	4713.31	Runge and Paschen.
Assumed	..	4861.50	16.2	46	0.024	4861.51	13.9	26	0.046	4861.53	$H\beta$. Rowland.
Assumed	..	4922.10	7.7	7	±0.097	4922.10	8.7	15	±0.048	4922.10	Runge and Paschen.

NOTE.—The probable errors in columns 6 and 10 of Table I are based on the agreement of the wave-lengths deduced from the several plates. These probable errors do not include the systematic uncertainties (of the order of one or two hundredths of an Angstrom) affecting the determination of wave-lengths by the corrected Hartmann interpolation curve.

In view of presence of effects in the light curve due the light of the "companion" of δ Orionis, it would seem that Hartmann's statement with reference to the absence of effects due to lines of the second component might well be reconsidered. Accordingly, during my own measures, I have watched carefully for the lines of this second component, but with uncertain success. At phases near velocity minimum I have measured on four of my plates close lines of intensity "3" on the edge of longer wave-length of some of the stronger lines in seven cases, giving a mean value of + 70 km. Whereas it is possible that these satellites belong to the first component, velocities consistent with the other lines are obtained by considering that they do not. If these satellites are due to a second component, this would indicate that the mass of this body is about 1.8 that of the primary and we would expect to find similar lines in a position corresponding to a negative displacement of about 40 km., at the phase of the velocity maximum of the primary; and at this phase there are five or six lines on four or five plates which might be ascribed to this second component. But obviously the evidence here is very weak. If the lines of the second component are strong enough to be seen it is possible that they are always hopelessly blended with the lines of the principal star. It is possible that some of the "structure" observed in the lines of δ Orionis is attributable to the lines of the second component as well as to the causes suggested by Hartmann; and also the possibility remains that anomalous dispersion plays a part here as suggested by Julius.

The structure of the lines in δ Orionis' spectrum presents an interesting but difficult problem. In the case of λ 4089 the variations of the line are so complex that I have not used it in velocity determination, though in ε Orionis the same line yields satisfactory results. On all the lines, my studies, like those of Hartmann, have brought out little evidence of relation between phase and structure change of lines.

One peculiarity, frequently observed in the lines of this spectrum, is an asymmetry due to greater diffuseness of one edge. It will be remembered that Schlesinger found that these shadings in the lines of the spectrum of λ Tauri were always toward the normal position of these lines. For three of the lines ($H\gamma$, λ 4471 and $H\beta$) in the spectrum of δ Orionis, the writer finds 100 cases of symmetry, 26 cases with shadings toward the normal positions of the lines and 14 cases with shading away from it. Close absorption was observed more frequently on the side toward the normal position of the line, than on the far side, but this effect in δ Orionis is not pronounced.

On three spectrograms of the visual region of the spectrum of δ Orionis the writer has measured the better lines for approximate wave-length determination and has estimated the intensities of these lines on the scale used in Table I. The results compared with those for ε Orionis are given in Table II. In the case of the identified lines the wave-lengths in this table were assumed. The relative weakness of $H\beta'$ in ε Orionis was not unexpected but that of $H\alpha$ had not been anticipated. Possibly the emission seen clearly at the edges of the $H\gamma$ and $H\beta$ lines has increased in this region at the expense of the enclosed absorption. In view of the faintness of K in δ Orionis, the absence of measurable impressions of the D lines of sodium is not unexpected.

TABLE II. WAVE-LENGTHS IN THE VISUAL REGION.

δ Orionis λ	Int.	ε Orionis λ	Int.	Identification
4862	16	4862	14	$H\beta$. Hydrogen.
5016	5	5016	8	Helium.
5414	8			$H\beta'$. Hydrogen.
5448	6			
		5653	5	
5876	12	5876	12	D_3. Helium.
		5890	3	D_2. Sodium.
		5896	3	D_1. Sodium.
6086	7			
6275	15	6275	10	
6280	7			
6328	6			
6563	10	6563	6	$H\alpha$. Hydrogen.

FORMER RADIAL VELOCITIES.

The earliest known velocities of δ Orionis were determined by Vogel and Scheiner from four plates made in the years 1888 to 1891. Because of the historic value of these observations they are given in the accompanying table. The

first measures show no evidence of variation, but the revised measures, made by Vogel ten years later with a knowledge of the established variation, are not inconsistent with later results. These early velocities were determined entirely from the Hγ line, across which fell the artificial line of the same element, making accurate measures exceedingly difficult.

TABLE III. EARLY POTSDAM OBSERVATIONS.

DATE	GR. M. T.	FIRST VEL.	REVISED VEL.	RESIDUAL
1888	Dec. 10.37	— 3 km.	— 9 km.	+ 10 km.
1889	Jan. 5.34	± 0	+ 4	— 24
1891	Feb. 26.26	+ 2	— 55	— 6
	27.26	+ 4	+ 13	— 35

The velocity variation of δ Orionis was discovered by M. Deslandres from eleven spectrograms made in December, 1899, and the following month, with a new spectrograph attached to the 62 cm. refractor of the observatory at Meudon. From these eleven observations, Deslandres derived a period of 1.92 days and concluded that the orbit was highly eccentric.

After the publication of Deslandres' discovery, which was communicated to the Paris Academy on February 12, 1900, confirmatory observations were made at once at Potsdam and, in the following season, by Wright at the Lick Observatory. But the velocity variation observed at Potsdam did not conform to Deslandres' period and since a fuller investigation seemed desirable, partly perhaps because of the lack of variation in the early Potsdam velocities, a set of thirty-seven one-prism spectrograms was made by Hartmann with the Potsdam 80 cm. refractor in the winter months of 1901-2 and 1902-3. The dates of these observations and the corresponding velocities will be found in Table IV of this paper.

TABLE IV HARTMANN'S POTSDAM OBSERVATIONS. (Spectrograph I.)

DATE		GR. M. T.	PHASE DAYS	VELOCITY KM.	RESIDUAL KM.	WT.
1901	Nov.	23.421	0.836	+ 63.5	+ 4.0	1.0
1902	Jan.	13.305	0.128	— 3.3	+ 12.8	0.7
		.399	0.222	+ 6.1	+ 13.0	0.5
		14.356	1.178	+ 92.2	— 6.0	0.4
		.441	1.263	+ 110.5	+ 5.0	0.7
		16.357	3.179	+ 27.0	+ 4.4	1.0
	Feb.	4.424	5.049	— 65.0	— 1.2	1.0
		10.368	5.260	— 45.1	+ 11.8	1.0
		11.256	0.416	+ 17.8	+ 4.8	1.0
		12.240	1.400	+ 124.9	+ 8.7	0.4
		13.224	2.384	+ 107.1	+ 1.8	1.0
		14.226	3.386	+ 3.9	+ 2.0	1.0
		15.196	4.356	— 63.0	— 1.8	1.0
		16.209	5.369	— 52.3	— 0.8	1.0
	Mar.	5.264	5.227	— 59.6	— 1.6	0.7
		6.226	0.457	+ 27.3	+ 8.7	1.0
		11.305	5.535	— 43.5	— 2.5	1.0
		12.235	0.733	+ 45.4	— 4.5	1.0
		13.232	1.730	+ 128.4	— 2.0	1.0
		14.238	2.736	+ 68.7	— 3.0	0.7
	Apr.	2.259	4.559	— 79.5	— 13.0	1.0
		2.307	4.607	— 60.0	+ 7.3	1.0
		9.295	0.131	— 30.0	— 14.5	0.7
		10.282	1.117	+ 81.2	— 9.6	1.0
	Dec.	11.385	5.456	— 49.3	— 3.0	1.0
		12.370	0.709	+ 47.2	+ 0.3	1.0
		13.367	1.706	+ 128.7	— 1.2	1.0
		14.459	2.798	+ 56.1	— 8.6	1.0
1903	Jan.	9.339	0.016	— 32.7	— 8.0	0.7
		12.391	3.067	+ 38.2	+ 2.9	0.7
		13.342	4.018	— 46.4	— 1.4	1.0
		14.320	4.996	— 69.3	— 4.1	1.0
		17.355	2.299	+ 127.1	+ 14.3	0.5
	Feb.	7.369	0.383	0.0	— 10.0	1.0
	Mar.	7.228	5.312	— 54.9	— 1.0	0.5
		12.244	4.595	— 61.2	+ 6.2	0.5
		15.256	1.875	+ 135.4	+ 5.0	1.0

Hartmann's memorable discussion of these observations is found in the *Astrophysical Journal*, Volume 19, pp. 268 to 285. On the basis of his own and the early revised Potsdam measures he deduces an apparent period of 5.7325 ± 0.0002 days for the velocity oscillation and through a preliminary reduction derives the remaining orbital elements:

$$e = 0.10334,$$
$$\omega = 339^\circ\ 18'.9,$$
$$T = 1902,\ \text{Feb. } 12.35,$$
$$K = 100.8\ \text{km.},$$
$$a \sin i = 7{,}906{,}600\ \text{k.m.},$$
$$m_1^3 \sin^3 i/(m_1 + m)^2 = 0.601\odot.$$

On the basis of the latter quantity he considers that the total mass of the system is certainly greater than the solar mass, and probably of the order of from five to ten times the solar mass.

Possibly the most interesting result in his

paper is found in the statement, ". . . the calcium line at λ 3934 does not share in the periodic displacements of the lines, caused by the orbital motion of the star." This discovery has raised a problem which, notwithstanding much well directed research, does not appear to be fully solved. Hartmann's ingenious explanation for this remarkable observation is found in ". . . the assumption that, at some point in space in the line of sight between the sun and δ Orionis, there is a cloud which produces this (K) absorption."

The importance of Hartmann's observations of δ Orionis, especially in connection with the Ann Arbor velocities, is such that a least square solution has been made in connection with the reductions of the present paper; and as a preliminary step normal places have been formed in Table V. It is not stated whether the times of observation have been reduced to the sun but the correction involved may be omitted here. The phases have been computed on the basis of a preliminary period, $P = 5.73248 \pm 0.000,022$ days, determined by a combination of Potsdam and Ann Arbor observations. The epoch adopted is 1900, Feb. 24. 2800, G. M. T. The hundredth of a kilometer occurring in this table is, of course, of little significance except as a check upon the computations. In forming the normal places, it was necessary to adopt a system of weighting for the individual plates. This raised some interesting questions which may now be discussed.

TABLE V. NORMAL PLACES (HARTMANN'S OBSERVATIONS).

WEIGHTS BASED ON NUMBER OF LINES MEASURED.

NO.	PHASE DAYS	VELOCITY KM.	RESIDUAL KM.	WT.
1	0.132	− 11.4	+ 2.0	1.000
2	0.421	+ 15.3	+ 0.6	0.714
3	0.758	+ 54.4	+ 2.9	0.643
4	1.206	+ 97.1	− 1.7	0.964
5	1.770	+ 131.0	− 0.5	0.679
6	2.332	+ 118.8	+ 5.9	0.536
7	2.766	+ 63.5	− 7.1	0.500
8	3.199	+ 23.6	+ 2.0	0.714
9	4.177	− 55.2	+ 1.3	0.464
10	4.588	− 66.2	+ 1.1	0.821
11	5.022	− 66.5	− 3.0	0.393
12	5.266	− 53.8	+ 0.7	0.821
13	5.453	− 48.4	− 3.9	0.750

WEIGHTS BASED ON MEAN ERRORS.

NO.	PHASE DAYS	VELOCITY KM.	RESIDUAL KM.	WT.
1	0.117	− 16.78	− 0.19	0.9
2	0.419	+ 14.98	+ 1.40	1.0
3	0.759	+ 52.06	+ 0.02	1.0
4	1.215	+ 98.83	− 2.10	0.8
5	1.770	+ 131.28	+ 0.35	1.0
6	2.355	+ 114.02	+ 5.74	0.5
7	2.772	+ 61.29	− 6.64	0.6
8	3.227	+ 20.97	+ 2.38	0.9
9	4.187	− 55.67	− 0.30	0.7
10	4.586	− 68.09	− 0.68	0.8
11	5.022	− 67.25	− 2.36	0.7
12	5.261	− 51.99	+ 4.73	0.7
13	5.453	− 48.55	− 1.89	1.0

The weighting of velocities obtained from plates containing stellar spectrum lines relatively few in number and differing widely in quality, is always attended with difficulties. In connection with his own observations of δ Orionis the author has adopted a system, described below, which seems to him satisfactory in determining the probable worth of a plate. But for the reduction of observations published by others the data are usually not available for the use of this system.

Hartmann has published for each velocity of δ Orionis the number of lines measured and the mean error deduced presumably from the internal residuals of the lines on each plate. In general it would seem reasonable to assume that the weight to be assigned the velocity deduced from one plate, of a number of the same star, should increase with the number of lines measured, in which case we should expect the mean error of the velocity derived from a plate to decrease with an increase in the number of lines used—though in no simple relation since in a velocity based on measures of more than the average number of lines available on plates of a given star, more than the usual proportion of poor lines are frequently included. Referring to the observations here considered we find that the mean errors do not stand in the expected relation to the number of lines. The average number of lines measured on each of the plates is almost exactly seven. And the average mean error for the whole set of plates is ± 5.6 km. For the

eleven plates having from eight to ten measurable lines the average mean error is ± 6.5 km.; and for the sixteen plates having from two to six measurable lines the average mean error is ± 5.5 km. Referring also to the residuals for these plates from Hartmann's velocity curve we find that the mean absolute residual for the plates containing more than seven lines is 6.5 km., while that for the plates containing less than seven lines is 3.9 km. It is possible that the lines added in making up the larger total of any plate received too much weight in the mean. It seems probable, however, that certain lines, for which the assumed wave-lengths yielded velocities more discordant than the average, were usually included in the measures of plates having the greater numbers of lines available.

If this be the case it would seem that the measures based on a greater number of lines per plate may be of greater value as yielding absolute velocities under these circumstances, whereas the velocities from plates on which lines equal to or somewhat less than the average in number are measured, possess greater relative accuracy. Accordingly plates of this latter class should receive the greater weight in connection with orbital determination, unless the necessary steps have been taken to reduce all wave-lengths used to a homogeneous system.

Obviously it would be unsafe to make the weight of each plate inversely proportional to the square of its mean error. It has seemed better to divide the plates into groups according to the number of lines measured, to derive the average mean error of each group, to plot these average mean errors with number of lines measured as abscissae, and to take from a smooth curve, drawn through such plotted points, the mean error, corresponding to the number of lines measured on any plate, as the best mean error for that plate. The mean errors and weights thus derived are given in the following table. The curve of mean errors here derived is quite similar to though flatter than the corresponding curve of average residuals based upon Hartmann's orbital elements.

TABLE Va. DERIVATION OF WEIGHTS.

No. Lines	Mean Error: Average Computed km.	Mean Error: From Curve km.	Weight	No. Plates
10	± 8.4	∓ 8	0.4	1
9	6.9	7	0.5	4
8	6.1	6	0.7	6
7	4.5	5	1.0	10
6	5.4	5	1.0	13
5	3.5	5	1.0	1
4	...	6	0.8	0
3	4.7	6	0.7	1
2	9.5	8	0.4	1

A practice solution of the observations of Table IV using weights directly proportional to the numbers of lines was carried out by Messrs. W. C. Rufus and L. M. Coffin at this observatory. Since these elements resulting from this solution are of interest in connection with the quantities deduced with modified weights, the details of the work may be briefly given.

The data of the normal places are given in columns 2 to 5 of Table V. The preliminary elements were computed by the forty-five degree chordal method.

Preliminary Elements

$P = 5.73248$ days,
$e = 0.096$,
$\omega = 347°\ 41'$,
$T = 1902$, Feb. 12.508,
$K = 100.0$ km.,
$\gamma = +23.22$ km.

The results of the least square solution follow. Though the maximum difference between final velocities computed with elements and from equations was somewhat large (0.46 km.) a second solution would yield unimportant changes. By this solution, the sum of the weighted squares of the residuals for the normal places was reduced from 1165 to 753.

Elements (Weights Based on Number of Lines)

$P = 5.73248 \pm 0.000{,}022$ days (assumed),
$e = 0.095 \pm 0.009$,
$\omega = 3°\ 41' \pm 6°.5$,
$T = 1902$. Feb. 12.742, ± 0.102 days,
$K = 99.98$ km.,
$\gamma = +22.80$ km.,
$a \sin i = 7{,}847{,}00$ km.,
$m_1^3 \sin^3 i/(m_1 + m)^2 = 0.587 \odot$.

The probable errors of the elements here are derived from the residuals for the normal places. In this case these probable errors would be about fifteen per cent larger if based on the individual plate residuals.

In the second least square solution of Hartmann's observations, which was made by the writer, the plate velocities were weighted as in column 6 of Table IV on the basis of Table Va. The data for the normal places are contained in columns six to nine of Table V. The weights in column nine are directly proportional to the sum of the weights of the plates combined into any normal place. Except for the change of weights, the data are used as in the first solution.

Assuming as preliminary the elements resulting from the first solution, and employing Schlesinger's adaptation of the formulae of Lehmann-Filhes, the normal equations become

$$\begin{array}{llllll}
+10.60\,\Gamma & & & & & \\
-1.836\,\kappa & -2.498\,\pi & +4.857\,\epsilon & -1.913\,\tau & +8.11 & =0 \\
+5.14 & +0.805 & -0.298 & +0.540 & -2.74 & =0 \\
 & +5.459 & -1.457 & +4.465 & -2.20 & =0 \\
 & & +3.420 & -1.134 & +3.53 & =0 \\
 & & & +3.677 & -1.14 & =0
\end{array}$$

The values of the unknowns are found to be

$$\Gamma = -0.563,\ \kappa = -0.241,\ \pi = +19.84,$$
$$\epsilon = +0.237,\ \tau = -23.95.$$

From these the *final elements* resulted:

FINAL ELEMENTS, δ ORIONIS (POTSDAM).

$P = 5.73248 \pm 0.000{,}022$ days (assumed),
$e = 0.0939 \pm 0.0089$,
$\omega = 352^\circ.3 \pm 6^\circ.9$,
$T = 1902$, Feb. 12.562 ± 0.108 days,
$K = 99.76 \pm 1.06$ km.,
$\gamma = +22.14$ km.,
$a \sin i = 7{,}829{,}000$ km.,
$m_1^3 \sin^3 i/(m_1 + m)^2 = 0.583\,\odot$.

By this solution the sum of the weighted squares of the residuals for the normal places was reduced from 922 to 772. The probable error of a normal place of weight one proves to be $\pm$ 2.10 km. and that of the weakest normal place, $\pm$ 3.0 km. In view of the magnitude of these quantities, the discrepancies due to the rejection of second order terms in the least square solution, amounting in the maximum to 0.28 km., and averaging 0.12 km., indicates that a repetition of the solution would lead to no important changes.

The curve corresponding to these elements is shown as a full line in the upper figure of Plate XX. Residuals scaled approximately from this curve for the several plates are given in the fourth column of Table IV. On the basis of these residuals the probable error of a plate of weight one is $\pm$ 4.5 km., and for a plate of average weight, $\pm$ 4.9 km. The value of this latter quantity corresponding to Hartmann's elements was $\pm$ 5.1 km.

For comparison with the new value of the velocity of the system, we may quote Hartmann's velocity from the fixed K line of calcium: + 16 $\pm$ 1.2 km. Though the wave-length upon which this velocity was based is not given it was presumably very close to the value due to Rowland.

Comparing the two sets of elements based on two systems of weights it will be seen that the differences are not greater than we might expect, in view of the probable errors, from two different sets of observations. It is interesting to note that such differences may arise between the results of two solutions of the same observations each based on a system of weights which any computer might adopt. Apparently the question of weights is one to which the computer should give close attention. In connection with the Ann Arbor observations this point will be further discussed.

THE ANN ARBOR RADIAL VELOCITIES.

The observations of the spectrum of δ Orionis made at the Detroit Observatory include seventy-four measurable spectrograms all of which were made with a single prism spectroscope attached to the $37\frac{1}{2}''$ Reflector. For a detailed description of these instruments the reader is referred to earlier papers in this volume. With a few exceptions the spectrograms were made upon lantern slide plates with average exposures of 8 to 10 minutes. For the study of the K line more especially, the fine grained plates were well nigh indispensable. Four plates were sensitized in the visual region.

The pertinent data in connection with these observations are found in Table VI. The phases, which were first computed with the period,

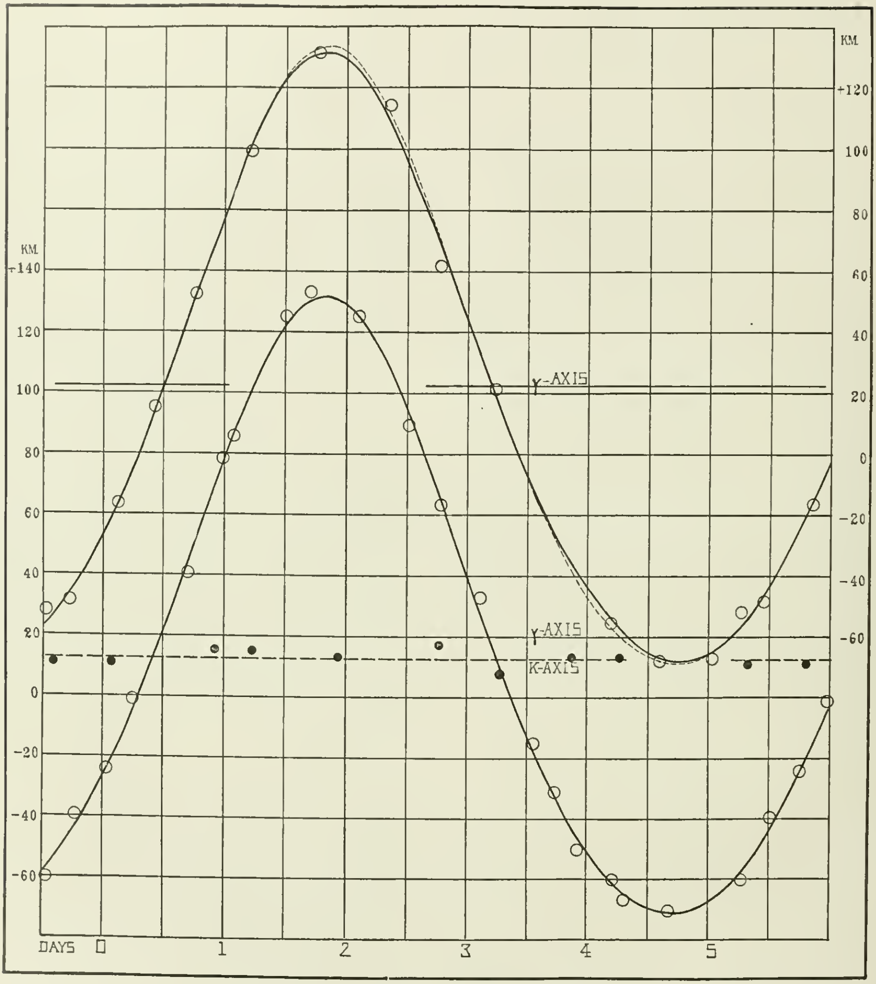


PLATE XX. VELOCITY CURVES OF δ ORIONIS.
OBSERVATIONS OF UPPER CURVE BY HARTMANN. 1901-1903.
LOWER CURVE BY CURTISS. 1912-1914.

5.73248 days, are based on the epoch, 1913, Sept. 11.410. The small corrections necessary to reduce these phases to the sun and to correct for the final period have been applied.

Thirteen lines, indicated in Table I, were used to determine absolute velocities from the plates of δ Orionis and three additional lines, λ's 4200, 4541, and 4650, were used to improve the relative values of the velocities. In determining the velocities of column seven of Table VI, the wave-

TABLE VI. THE ANN ARBOR OBSERVATIONS.

NO. OF PLATE	OBSERVER	DATE, G. M. T.	PHASE	OSCILLATING LINES NO.	WT.	VEL.	RESID.	K LINE VEL.	WT	H LINE VEL.	WT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		1912 d	d			km.	km.	km.		km.	
323	Curtiss	Mar. 12.602	2.507	9	12	+ 87.0	− 6.5	..	...	..	...
324	Curtiss	12.608	2.513	8	12	+ 86.2	− 5.6	..	...	..	...
1524	Mellor	Nov. 29.878	1.096	9	10	+ 88.8	+ 0.1	+ 12	2	..	...
1525	Mellor	29.884	1.102	8	11	+ 90.7	+ 1.2	+ 14	2	+ 16	1
1535	Curtiss	30.735	1.953	7	6	+ 129.9	+ 0.0	+ 18	1	..	...
1550	Curtiss	Dec. 14.777	4.530	4	3	− 74.6	− 4.8	..	...	..	...
		1913									
1578	Curtiss	Jan. 12.763	4.852	5	8	− 67.7	+ 2.5	+ 23	1	..	...
1583	Mellor	24.672	5.296	8	10	− 67.5	− 11.3	+ 7	2	+ 23	1
1584	Mellor	24.696	5.320	7	9	− 62.8	− 7.5	..	...	..	...
1596	Mellor	28.687	3.578	5	7	− 20.6	− 0.1	..	...	..	...
1597	Mellor	28.699	3.590	7	6	− 15.5	+ 7.0	..	...	..	...
1604	Curtiss	Feb. 8.667	3.095	7	9	+ 33.0	+ 5.6	± 0	½	..	...
1605	Curtiss	8.687	3.114	7	8	+ 31.9	+ 6.0	± 0	2	+ 2	1
1618	Mellor	17.678	0.638	7	7	+ 30.3	− 8.0	..	...	..	...
1619	Mellor	17.689	0.649	5	6	+ 44.0	+ 4.5	..	...	+ 16	1
1654	Curtiss	Apr. 6.610	2.706	4	4	+ 60.0	− 10.2	..	...	..	...
2325	Mellor	Sept. 22.887	0.013	9	7	− 28.0	− 3.3	+ 11	1	..	...
2349	Mellor	Oct. 3.889	5.283	10	12	− 64.7	− 7.9	+ 7	1½	..	...
2350	Mellor	3.895	5.289	7	9	− 51.2	+ 5.3	+ 5	1	..	...
2370	Curtiss	9.815	5.477	6	8	− 36.8	+ 9.0	+ 6	1	+ 18	½
2371	Curtiss	9.835	5.497	6	10	− 37.0	+ 7.6	+ 19	1	..	...
2407	Curtiss	25.800	4.265	7	6	− 60.1	+ 3.4	+ 15	1	+ 15	1½
2408	Curtiss	25.818	4.283	9	9	− 67.2	− 3.0	+ 19	1	..	...
2420	Curtiss	Nov. 1.776	5.510	7	8	− 52.8	− 8.7	+ 12	2	+ 5	1
2421	Curtiss	1.805	5.539	9	8	− 42.4	− 0.2	+ 12	1	+ 16	2
2462	Mellor	Dec. 3.794	3.133	11	10	+ 30.1	+ 6.2	..	..	..	...
2463	Mellor	3.815	3.154	9	7	+ 25.9	+ 4.4	..	...	..	...
2466	Curtiss	4.818	4.158	8	8	− 50.4	+ 8.3	+ 8	2	+ 24	1½
2467	Curtiss	4.844	4.184	8	6	− 65.3	− 5.2	+ 13	2	..	...
2478	Mellor	8.819	2.427	7	6	+ 102.9	+ 0.4	..	...	+ 29	½
2479	Mellor	10.715	4.323	6	6	− 70.1	− 5.0	+ 17	2	..	...
2480	Mellor	10.729	4.337	10	8	− 69.5	− 4.0	+ 10	2	..	...
2491	Curtiss	13.792	1.668	9	9	+ 132.5	− 3.4	+ 7	2	..	...
2492	Curtiss	13.837	1.713	9	9	+ 136.3	+ 6.3	..	...	..	...
2493	Curtiss	13.859	1.735	6	5	+ 127.6	− 1.8	..	...	..	...
2494	Curtiss	13.892	1.767	2	2	+ 131.7	+ 0.8	..	...	..	...
2498	Merrill	14.680	2.555	8	9	+ 86.6	− 2.4	+ 6	1	+ 19	½
2512	Curtiss	18.774	0.918	7	7	+ 73.1	+ 4.0	..	...	..	...
2513	Curtiss	18.833	0.977	9	6	+ 87.3	+ 1.6	..	...	..	...
2538	Mellor	Jan. 13.694	3.907	9	8	− 50.6	− 4.8	+ 12	1	..	...
2539	Mellor	13.714	3.927	9	8	− 57.3	− 10.3	..	...	..	...
2546	Mellor	17.708	2.188	7	8	+ 125.1	+ 6.2	+ 21	1	+ 39	1
2547	Mellor	17.728	2.208	8	7	+ 122.6	+ 4.8	+ 12	1	..	...
2560	Mellor	Feb. 4.731	3.013	6	5	+ 46.5	+ 0.0	..	...	..	...
2565	Curtiss	5.630	3.912	7	8	− 44.7	+ 1.8	− 2	1	..	...
2566	Curtiss	Feb. 5.657	3.939	10	11	− 48.8	− 1.4	+ 19	2	..	...
2569	Curtiss	7.695	0.244	9	10	− 4.2	+ 0.3	+ 17	1	..	...
2570	Curtiss	7.707	0.256	13	12	+ 1.7	+ 4.5	+ 6	1	+ 18	½
2577	Mellor	11.681	4.230	8	8	− 64.8	− 2.7	..	...	..	...
2578	Mellor	11.687	4.235	7	6	− 60.5	+ 1.0	..	...	..	...

TABLE VI. THE ANN ARBOR OBSERVATIONS (Continued).

NO. OF PLATE	OBSERVER	DATE, G. M. T.	PHASE	OSCILLATING LINES NO.	WT.	VEL.	RESID.	K LINE VEL.	WT	H LINE VEL.	WT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		1914 d	d			km.	km.	km.		km.	
2579	Curtiss	12.654	5.202	8	9	— 54.7	+ 5.6	..	..	..	...
2580	Curtiss	12.675	5.223	8	9	— 56.5	+ 3.0	— 9	½	..	...
2585	Curtiss	19.605	0.688	11	10	+ 40.5	— 2.2	+ 20	2	..	...
2588	Curtiss	19.642	0.725	9	10	+ 45.2	— 3.0	+ 12	1	..	...
2589	Curtiss	19.654	0.737	12	13	+ 41.5	— 8.0	..	...	..	...
2599	Mellor	24.672	0.023	7	8	— 20.7	+ 4.0	+ 9	1	..	...
2600	Mellor	24.679	0.030	9	8	— 23.9	+ 0.4	..	...	..	...
2611	Mellor	Mar. 9.612	1.496	8	7	+ 119.8	— 0.2	+ 19	2	..	...
2612	Mellor	9.621	1.505	7	7	+ 129.9	+ 7.8	..	...	..	...
2623	Mellor	11.623	3.507	9	9	— 15.6	— 0.3	— 10	1	..	...
2624	Mellor	11.641	3.525	8	10	— 11.5	+ 5.0	+ 21	1	..	...
2641	Mellor	16.623	2.774	10	8	+ 66.5	+ 2.6	..	...	..	...
2642	Mellor	16.631	2.782	12	11	+ 62.5	— 0.5	+ 14	1	+ 1	1
2649	Curtiss	17.571	3.722	10	11	— 30.1	+ 1.9	+ 18	1	..	...
2650	Curtiss	17.582	3.733	10	9	— 32.6	+ 0.8	+ 10	½	..	...
2655	Curtiss	20.569	0.987	12	12	+ 71.1	— 6.8	+ 15	2	— 8	½
2657	Curtiss	20.599	1.017	10	10	+ 83.8	+ 3.5	..	...	+ 30	1
2659	Curtiss	20.615	1.033	10	9	+ 83.4	+ 0.4	..	...	..	...
2664	Curtiss	Apr. 5.556	5.508	8	9	— 33.4	+ 10.3	..	...	+ 8	1
2665	Curtiss	5.572	5.524	5	4	— 39.4	+ 3.4	..	...	..	...
2666	Curtiss	5.595	5.547	10	10	— 36.9	+ 2.1	..	...	..	...
2670	Curtiss	8.576	2.794	10	8	+ 62.1	— 0.2	+ 28	2	+ 32	1
2679	Curtiss	12.565	1.051	8	10	+ 78.7	— 6.2	+ 10	1	..	...
2689	Curtiss	13.569	2.055	10	10	+ 120.6	— 5.9	..	...	..	...

lengths were corrected by an amount sufficient to reduce to zero the weighted mean of the residuals of each line. These corrected wave-lengths are those of column three of Table I.

During the return measures weights were assigned to each line based on the observer's judgment of its availability for velocity determination. With these weights the preliminary velocities for each plate were determined and the wave length correction was determined which reduced to zero the weighted mean of the residuals for each line on all the plates. The final residuals for all of the measures of any line were then employed in the usual way to determine the probable error of a single measurement of that line. The average value of the weights originally assigned to that line was then compared with this probable error and in the cases of five lines it was found that the assigned original weights had been too high or too low by small amounts. On this basis the original weights were corrected, and with this new set of weights the final velocities of column seven, Table VI, were determined. The plate weights in column six are the sums of the weights of the lines from which the corresponding velocities in column 7 were determined.

The normal places of Table VII are based directly on the data of Table VI, the weights, with one exception, being proportional to the sum of the weights of the plates entering into any combination. In the case of the seventh normal place the large residual at once led to suspicion, especially since the agreement among the plates included was very good. It was recognized that a possible explanation for the observed positive displacement of the lines of this normal place might be found in circumstances attending the principal light minimum which occurred within a few minutes of this normal phase. Though the degree of eclipse is small it was thought possible that the interposition of regions of the "atmosphere" of the secondary might produce the displacement observed. On the other hand, Hartmann has two observations near this phase

which, though similarly displaced, exhibit the effect in a considerably smaller degree. Though the first inclination was to omit this normal place from the least square solution because of the uncertainty involved, in view of conflicting considerations, including the absence of a clear case for rejection, it was decided to use the five observations in question with half the normal weight.

TABLE VII. NORMAL PLACES, OSCILLATING LINES.

NO. (1)	PHASE (2) days	LIMITS OF PHASE (3) d		d	VEL. (4) km.	RESID. (5) km.	WT. (6)
1	0.023	0.01	to	0.03	− 24.03	+0.83	0.41
2	0.250	0.24	to	0.26	− 0.99	+2.87	0.39
3	0.696	0.63	to	0.74	+ 40.58	−4.20	0.79
4	0.983	0.91	to	1.02	+ 78.12	+0.90	0.61
5	1.073	1.03	to	1.11	+ 85.50	−1.29	0.70
6	1.500	1.49	to	1.51	+124 84	+2.88	0.23
7	1.706	1.66	to	1.77	+132.06	+3.24	0.44
8	2.102	1.95	to	2.21	+124.92	+1.12	0.54
9	2.508	2.42	to	2.56	+ 89.01	−3.69	0.67
10	2.774	2.70	to	2.80	+ 63.09	−1.28	0.56
11	3.109	3.01	to	3.16	+ 32.52	+6.02	0.32
12	3.543	3.50	to	3.60	− 15.39	+2.29	0.56
13	3.727	3.72	to	3.74	− 31.22	+1.86	0.35
14	3.922	3.90	to	3.94	− 50.26	−3.52	0.61
15	4.202	4.15	to	4.24	− 60.03	+1.15	0.49
16	4.302	4.26	to	4.34	− 66.87	−2.04	0.49
17	4.769	4.53	to	4.86	− 70.32	+0.58	0.20
18	5.270	5.20	to	5.32	− 60.01	−2.70	0.98
19	5.514	5.47	to	5.55	− 39.42	+3.85	1.00

From a preliminary solution these approximate elements were adopted:

$$
\begin{aligned}
P &= 5.73248 \text{ days},\\
e &= 0.100,\\
\omega &= -0^\circ.70,\\
T &= 1913, \text{ Sept. } 13.2203,\\
K &= 101.00 \text{ km.},\\
V_0' &= +30.00 \text{ km.}
\end{aligned}
$$

The normal equations are:

$$
\begin{array}{llllll}
+10.34\,\Gamma & & & & & \\
-1.461\,\kappa & -0.858\,\pi & +4.950\,\epsilon & -0.714\,\tau & -2.07 & =0\\
+5.156 & +0.034 & -0.269 & +0.003 & -0.12 & =0\\
 & +5.184 & -0.653 & +4.484 & +0.10 & =0\\
 & & +3.178 & -0.552 & -1.55 & =0\\
 & & & +3.704 & -0.11 & =0.
\end{array}
$$

The values of the corrections are:

$$
\delta e = -0.0031,\ \delta\omega = -0^\circ.568,\ \delta T = -0^d.0084,
$$
$$
\delta K = +0.018 \text{ km.},\ \delta\gamma = +0.19 \text{ km.},
$$

and the *final elements* with probable errors are:

FINAL ELEMENTS, δ ORIONIS (ANN ARBOR)

$$
\begin{aligned}
P &= 5.732448 \pm 0.000{,}015 \text{ days}, \quad \text{Epoch, 1908,}\\
e &= 0.0969 \pm 0.00856,\\
\omega &= 358^\circ.73 \pm 1^\circ.92,\\
T &= 1913, \text{ Sept. } 13.2119 \pm 0.0760 \text{ days},\\
K &= 101.02 \pm 0.76 \text{ km.},\\
\gamma &= +20.09 \text{ km.},\\
a \sin i &= 7{,}926{,}000 \text{ km.},\\
m_1^3 \sin^3 i/(m_1+m)^2 &= 0.605 \odot.
\end{aligned}
$$

The residuals for the normal places based on these elements are found in the fifth column of Table VII. The difference between any residual as computed from the observation equations and from the final elements in no case exceeds 0.04 km. From these residuals the probable error of a normal place of weight one is found to be ± 1.66 km. The residuals for the individual plates as scaled approximately from the velocity curve are given in the eighth column of Table VI. On the basis of these residuals, the probable error of an average plate is found to be ± 3.7 km.

The final period given above was obtained by superposition of the Ann Arbor and Potsdam curves, both of which had been computed with the same preliminary value of the period, $P =$ 5.73248 days. This superposition showed that the average phase difference between the two curves was 0.023 days which is the phase error introduced by using the assumed period over an interval of 11 years and 3 months or 716 orbital periods, from 1902, June, to 1913, September. To remove this phase error a correction of −0.000,032 days ± 0.000,015 days must be applied to the assumed period, the probable error being estimated. A comparison of this final apparent period with that of Hartmann for Epoch, 1898 ± (P = 5.7325 ± 0.000,2 days) indicates that no changes have been established in this quantity by observations covering twenty-five years.

The velocity curve corresponding to my final elements is drawn in the lower figure of Plate

XX. To show at a glance the chief differences between the Potsdam and Ann Arbor curves, part of the latter is compared directly with the former in the dotted line curve of the upper figure. Where the dotted line is not drawn the coincidence is too close to be shown in this manner. Thus it will be seen that these two curves fit together with discrepancies nowhere greater than about 2.5 kms., which is very nearly the probable error of a good normal place. Considering the separate elements it is evident that they do not differ by amounts greater than the uncertainty of the determinations as indicated by the probable errors. No changes are indicated in the orbit of this system.

If the evidence given above, indicating a ratio of the masses of 1.8, be accepted, the values of $m \sin^3 i$ and $m_1 \sin^3 i$ become respectively, 0.81 and 1.46 times that of our sun. Since the bodies involved eclipse each other during their orbital revolution, it is probable that the factor, $\sin^3 i$, is greater than one-half.

Whenever available, the H and K lines have been measured at least once on all of the Ann Arbor spectrograms. The resulting velocities with their weights are given in the last four columns of Table VI. Because of the interference of the close Hϵ line only the simple weighted mean of the H line velocities has been derived. This proves to be $+ 17 \pm 2$ km.

TABLE VIII. NORMAL PLACES, THE K LINE.

NO. (1)	PHASE (2)	LIMITS OF PHASE (3)	VEL. (4)	RESID. (5)	WT. (6)	INTENSITY (7)
	days	d d	km.	km.		
1	0.065	5.6 to 0.3	+11.0	−1.5	0.5	2.8
2	0.924	0.6 to 1.1	+15.3	+2.8	0.6	3.2
3	1.229	1.1 to 1.5	+15.0	+2.5	0.6	2.3
4	1.930	1.6 to 2.3	+13.0	+0.5	0.5	3.3
5	2.769	2.5 to 3.2	+16.9	+4.4	0.4	2.7
6	3.265	3.1 to 3.7	+ 7.1	−5.4	0.6	3.2
7	3.864	3.7 to 4.0	+12.9	+0.4	0.6	3.5
8	4.256	4.1 to 4.4	+13.0	+0.5	0.9	2.7
9	5.322	4.8 to 5.6	+10.8	−1.7	1.0	3.0

Mean Velocity $+12.5 \pm 0.7$. Mean Intensity 3.0

The velocities for the K line are combined into normal places in Table VIII. and are plotted as full circles in the lower figure of Plate XX. As no variation is established in these velocities, a straight line corresponding to the mean velocity of $+ 12.5 \pm 0.7$ km. is drawn through them. This mean velocity, which is based on Rowland's wave-length of λ 3933.825, falls 7.6 km. below the velocity of the center of mass of the system. Hartmann's mean velocity for this line ($+ 16 \pm 1.2$ km.) based on a wave-length which is not given, falls 6.1 km. below his velocity for the system. Apparently, so far as comparison is possible, these results are in substantial agreement. Furthermore, Hartmann's conclusion, which must be construed within limitations, that the K line in the spectrum of δ Orionis does not participate in the oscillatory motion of the other lines, is here borne out in greater degree and extended to the H line. As pointed out by Hartmann these velocities for the fixed H and K lines differ but little from the velocity of the solar system in this direction ($V = + 18$ km.), but this observation seems to apply equally well to the velocity of the system of δ Orionis, as we might expect in the case of a Class B star.

ϵ ORIONIS.

The Total Light.

The visual magnitude of ϵ Orionis ($\alpha = 5^h 31^m$, $\delta = -1^\circ 16'$) as given in the Revised Harvard Photometry is 1.75 Apparently no variation of its brightness has been found, and this star has been used frequently as a comparison star in the study of the light variations of other objects.

The Spectrum.

Epsilon Orionis is a typical star of Class B. An excellent reproduction of its objective prism spectrum is found in *Harvard College Annals*, Volume 28, Plate I; and lists of approximate wave-lengths, with accompanying intensities, for the spectrum lines are found in Tables XXIII and XXIV of the same volume. A detailed record of the lines in this spectrum will be found in a "Catalog of 470 of the Brighter Stars" published by the Solar Physics Committee in 1902.

The wave-lengths resulting from the Ann Arbor measures are listed in Tables I and II, to which sufficient allusion has perhaps been made.

However attention might be called to the Carbon (?) group at λ 4649.5. On two-thirds of the plates of ϵ Orionis and on about 14 per cent of those of δ Orionis this group was measured as double. In ρ Leonis, of more advanced spectrum, it appears to be single and in practically the same position. It is suggested that this line is reversed in δ and ϵ Orionis. Reference might be made also to the presence of D1 and D2 in the spectrum of ϵ Orionis. It would be of importance to know whether these lines regularly accompany the sharp K line in Class B stars and exhibit the same behavior. In certain Novae this is known to be the case at some stages at least. The presence in the spectrum of ϵ Orionis, of dark lines in the positions of the D lines, was referred to by Campbell in 1894, who gives also a list of lines in δ and ϵ Orionis. [See *Astronomy and Astrophysics*, Vol. XIII, page 395.]

In commenting on the case of ϵ Orionis in the course of a three-prism study of twenty Orion stars, Frost and Adams remark, "All of the lines in its spectrum are extremely broad and ill-defined, and the accuracy of measurement is probably less than for any other star in the list." The lines in the spectrum of ϵ Orionis, though of poor quality, are, nevertheless, much superior to those in the spectrum of δ Orionis. The probable error of a single velocity determination from the best line ($H\gamma$) as measured on the Ann Arbor plates of δ Orionis was $\pm$ 7.2 km.; from the average line, about $\pm$ 10 km. For ϵ Orionis these quantities were $\pm$ 3.4 km. for the best line and about $\pm$ 6 km. for the average line. In many cases emission is present on both edges of absorption lines in ϵ Orionis and this serves to define these edges more clearly.

Former Radial Velocities.

Three early Potsdam velocities of ϵ Orionis with a range of 6.4 km. give a mean velocity of + 26.7 km. for the epoch, 1889.00. Four velocities of this star derived by Frost and Adams from spectrograms made with the Bruce Spectrograph during seven months following the date, 1901, Sept. 4, have a range of 2 km. and a mean value exactly in accord with that obtained at Potsdam twelve years earlier.

Fourteen velocities determined by Dr. O. J. Lee with single prism dispersion at Yerkes Observatory from spectrograms made during five years following 1903, Dec. 6, have a range of 21 km. and a mean value of + 27.8 km. The probable error of a single plate velocity on the basis of this mean is $\pm$ 3.7 km. which is too large to be accounted for by accidental errors. Frost has announced this star as a spectroscopic binary. Velocities from the narrow and sharp H and K lines, obtained for ten of these plates, give a mean of + 28 km. Though these H and K velocities differ either way from the velocities obtained from the broad lines by 6 km. on the average, Frost infers that these H and K lines share in the oscillations of the broad lines.

The Ann Arbor Radial Velocities.

The thirty Ann Arbor velocities from plates made on seventeen nights in 1913 to 1914 are given with necessary details in Table IX. The reduction including the weighting of lines, was carried out exactly as in case of δ Orionis. The weighted mean of the velocities from the broad lines in column four is + 25.6 km. $\pm$ 0.6 km. The residuals from this mean for each of the plates is found in column eight of the table. On the basis of these residuals the probable error of an average plate is found to be $\pm$ 3.7 km., and the mean residual, $\pm$ 4.41 km., quantities in very close accord with those deduced from Lee's results. Also the range of 18 km. is but three kilometers less than that shown by Lee's measures; and the mean of my measures is in accord with that obtained by all previous observers, within the limits of error of measures of spectra of this type.

In one or two ways it is possible to show that the probable error and mean residual for a single plate, derived above, are larger than we should expect. If ϵ_1 denote the average probable error of a plate deduced from the internal agreement of the velocities from the several lines of the plates of a given star of constant velocity; and if ϵ denote the probable error of a plate deduced from the comparison of velocities from these several plates of the same star; and, finally, if ϵ_2 denote that element of the probable error of a

TABLE IX. VELOCITIES OF ϵ ORIONIS.

NO. OF PLATE	OBSERVER	DATE, G. M. T.	BROAD LINES VEL.	NO.	WT.	P. E.	RESID.	K LINE VEL.	WT.	H LINE VEL.	WT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10	(11)	(12)
		1913 d	km.			km.		km.		km.	
1606	Curtiss	Feb. 8.705	+21.6	13	29	±1.3	−3.9	+24	1	..	...
1607	Curtiss	8.717	+28.0	14	17	1.4	+2.5	..	.	..	...
2422	Curtiss	Nov. 1.815	+27.7	13	18	1.8	+2.2	+22	2	+12	1
2423	Curtiss	1.822	+24.4	16	26	1.2	−1.1	+12	2	+14	1
2481	Mellor	Dec. 10.739	+30.2	16	20	1.3	+4.7	+20	2	+12	1
2482	Mellor	10.753	+30.0	14	20	2.5	+4.5	+12	2	..	...
2499	Merrill	14.698	+16.8	16	23	1.2	−8.7	+11	2	..	...
2514	Curtiss	18.845	+28.3	10	15	1.3	+2.8	+16	1	..	...
2515	Curtiss	18.855	+33.2	12	12	1.5	+7.7	..	.	..	...
		1914									
2540	Mellor	Jan. 13.725	+32.1	12	20	1.1	+6.6	+6	1	..	...
2541	Mellor	13.732	+33.1	6	6	2.7	+7.6	+14	1	..	...
2567	Curtiss	Feb. 5.676	+23.3	10	15	3.7	−2.2	+15	1	..	...
2568	Curtiss	5.695	+27.8	16	20	1.9	+2.3	+15	1	+5	½
2571	Curtiss	7.733	+26.9	20	27	1.0	+1.4	+20	1	..	...
2581	Curtiss	12.692	+28.8	19	31	1.5	+3.3	+1	1	+10	½
2582	Curtiss	12.706	+26.7	14	19	1.9	+1.2	+3	2	..	...
2590	Curtiss	19.670	+15.7	20	29	1.3	−9.8	+5	1	..	...
2639	Mellor	Mar. 16.592	+19.1	13	20	1.4	+6.4	+21	2	+20	½
2640	Mellor	16.610	+21.2	12	23	2.2	−4.3	+20	1	+28	½
2647	Curtiss	17.549	+24.1	18	25	0.9	−1.4	+23	2	+2	½
2648	Curtiss	17.561	+26.8	17	25	1.5	+1.3	+13	1	+31	1
2651	Curtiss	17.601	+29.3	19	28	1.6	+3.8	+17	2	+28	½
2654	Curtiss	20.562	+21.2	16	24	0.9	−4.3	±0	1	..	...
2656	Curtiss	20.590	+17.0	17	28	0.7	−8.5	+14	1	..	...
2658	Curtiss	20.607	+22.1	20	26	0.8	−3.4	+32	1	..	...
2667	Curtiss	Apr. 5.605	+30.4	20	26	1.7	+4.9	..	.	..	...
2668	Curtiss	5.617	+31.5	13	15	2.0	+6.0	..	.	..	...
2671	Mellor	8.583	+31.2	15	17	2.2	+5.7	+43	1	+21	1
2680	Curtiss	12.577	+33.5	15	22	1.5	+8.0	+13	1	..	...
2690	Mellor	13.579	+27.5	13	19	1.4	+2.0	..	.	..	...
Means			+25.6 ± 0.6 km.					+17.0 ± 2.5 k		+15.6 ± 1.2 km.	

given average plate which is introduced by causes other than those contributing to ϵ_1, we may write,

$$\epsilon^2 = \epsilon_1^2 + \epsilon_2^2.$$

The last quantity, ϵ_2, will depend largely upon systematic spurious displacements of the star and comparison spectra due to instrumental errors, variations in personal equation, systematic asymmetry of lines, etc. For different sets of plates made with a given spectrograph and measured by experienced observers, this element of the probable error of a single plate should be approximately constant. On the other hand, ϵ_1 will depend largely upon the relative accuracy of the wave-lengths and the measurability of the star lines.

From twenty plates of α Lyrae's spectrum, made here and measured by Mr. L. L. Mellor, it is found that

$$\epsilon = \pm 1.74 \text{ km.},$$
$$\epsilon_1 = \pm 1.45 \text{ km.},$$

and thus

$$\epsilon_2 = \pm 0.97 \text{ km.},$$

which is probably a little greater than the average value of this quantity.

Combining this value of ϵ_2 with the value of ϵ_1 (= ± 1.6 km.) found above for ϵ Orionis in Table IX, column 7, we deduce the value, ± 1.9

km., for the probable error (ϵ) of the velocity from a single spectrogram of this star. Further this same value for ϵ Orionis is obtained from differences between velocities from pairs of plates of this star made in rapid succession on the same night, the only assumption being that the velocity does not vary appreciably during the short interval involved.

In the light of this value for the probable error of a single plate velocity of ϵ Orionis it is apparent that the excessive magnitude of this quantity as deduced from the velocities of Table IX is attributable to the variable velocity of this star.

A good idea of the extent of the variation of the radial velocity of ϵ Orionis may be secured if we assume that this variation follows a sine curve with the forty-four velocities determined by Lee and the writer uniformly distributed along the time axis. For, if K represents the half amplitude of the assumed sine curve, the average of the absolute values of a large set of velocities distributed evenly along the time axis will be very nearly,

$$\frac{K\int_0^{\pi} \sin x\, dx}{\int_0^{\pi} dx},$$

which equals $2K/\pi$. This is the average quantity which enters into the residuals in column eight of Table IX as the result of the assumed velocity oscillation. Accordingly the element of the probable error of a single plate due to this effect upon these residuals is approximately $\pm\ 1.75K/\pi$, on the basis of the well known shorter formula for probable errors. Calling this ϵ_3, and the probable error of a single plate velocity based directly on the residuals in column 8 of Table IX, E, we may write,

$$E^2 = \epsilon^2 + \epsilon_3^2,$$

from which we derive a value for K of 5.7 km. and a velocity range of 11.4 km. This is probably only an approximate value of the velocity range, however, for the frequency curve of the Yerkes and Ann Arbor velocities of this star indicates an orbital eccentricity of about 0.3.

The range of variation of ϵ Orionis is so small that it is not strange that considerable difficulty has been experienced in finding a satisfactory period. If we plot along the time axis the twenty-eight velocities observed at Ann Arbor during the past winter (1913-1914), they at once suggest a sine curve with the elements: Period = 100 days, $K = 13$ km., $V = +\ 26.5$ km. But the probable error of a single observation as based on the residuals from this curve is $\pm\ 2.6$ km. which is still too large, though greatly reduced. Probably this apparent adherence to a long period variation is partly accidental but it certainly suggests some interesting commensurability of the true, and probably short, period with the day.

In writing an expression which shall connect the long period with some short period which shall be very nearly equal to some round fraction of a day, we may let p represent the long period; P, the short period; a, the rounded value of $1/P$; and dT, the interval by which the average hour of observing changes toward smaller values during the series of plates. Then

$$P = \frac{p - dT}{ap \mp 1}$$
$$= (\text{approx.})\ \frac{1}{a} \pm \frac{1}{a^2p} - \frac{dT}{ap}.$$

On the basis of these formulae and the value of 100 days for p, a number of different periods have been derived and tested. Of these the best are 0.49677 days and 0.33173 days. The observations when plotted with these periods suggest a sine curve with an amplitude of about ten kilometers with an average residual little if any smaller than that derived from the long period oscillation. On the whole it seems probable that further search for a period might better wait until more observations are available. An explanation, which usually is suggested when a small velocity range of short period is found in an early type star, might be offered here; namely, that the lines in this spectrum are really composite though never resolved. Under these circumstances, if the two components be of unequal brightness, capricious changes depending on the density of the

spectrogram might be measured in the positions of the lines.

In a set of preliminary reductions of the measures of the Ann Arbor spectrograms of ϵ Orionis, the H and K lines were included with the others in the mean velocity. When it became evident that these two lines were consistently displaced in the direction of shorter wave-lengths with reference to the other lines, the measures of them were segregated and collected with assigned weights in the last four columns of Table IX.

The weighted mean of the twenty-five velocities derived from the K line is $+15.6 \pm 1.2$ km., a result 9.5 km. less than the mean velocity derived from the broad lines on these same plates. The weighted mean of the eleven velocities from the H line is $+17.0 \pm 2.5$ km., a result 9.2 km. less than the mean velocity obtained from the broader lines on the same plates. It is interesting to observe that the final mean velocity from the calcium lines ($+16.0$ km.) is less than all but one of the plate velocities determined from the broader lines. It is also pertinent to note that the velocity from the K line in δ Orionis falls 7.6 kms. below the velocity of that system as deduced from the oscillating lines.

It remains to consider whether the displaced calcium lines follow the broader lines in their oscillations. If the calcium lines do oscillate in parallel with the broader lines it would be expected that the differences between the broad line velocity and that from the calcium lines of each plate would agree for the series better than do the calcium line velocities among themselves. However the reverse is the case. The average residual of the differences, broad lines minus calcium lines, from their mean is ± 6.7 km., which is reduced to ± 6.5 km. by taking into account the probable error of the broad line velocities, whereas the average residual of the calcium line velocities from their mean is ± 5.8 km. This is, within reasonable limits, the result which we would anticipate if the calcium lines were fixed and the broad lines were oscillating with a range of about 10 km., which is roughly the range of variation of the broad line velocities deduced above. In the case of the Yerkes Observatory velocities, the average difference between the broad line velocities and those from the calcium lines of each plate is ± 5.8 km. which is reduced to ± 5.6 km. by taking into account the probable error of the broad line velocities. At the same time the average residual of the calcium line velocities from their mean is ± 5.2 km., a difference in fair agreement with the Ann Arbor results. There seems to be little or no evidence to indicate that the calcium lines oscillate with the broad lines in ϵ Orionis.

The interesting difference of 12 km. between the mean velocity deduced from the calcium lines at Yerkes Observatory and that observed at Ann Arbor, only two km. of which is attributable to systematic discrepancy, may indicate a variation of the velocity derived from the H and K lines—possibly a variation of long period.

If we accept Hartmann's highly interesting hypothesis of a calcium cloud lying between the sun and certain stars in the constellation of Orion, the Ann Arbor measures furnish the following determinations of the radial velocity of this calcium medium with reference to the sun:

STAR	LINE	VELOCITY km.	WEIGHT
δ Orionis	K	$+12.5$	8.0
	H	$+17.2$	1.0
ϵ Orionis	K	$+15.6$	3.0
	H	$+17.0$	0.6

Velocity of calcium cloud, $+13.8$ km.

In view of the importance of comparison among determinations of this "calcium cloud" velocity at different epochs and with different instruments, it may be said that the presence of excellent *H* and *K* bright lines in the comparison spectrum of many of the Ann Arbor spectrograms of ϵ and δ Orionis has enabled the writer to check within a kilometer by direct measures the velocities from these lines as derived through the use of Rowland's wave-lengths.

SUMMARY.

The foregoing paper is devoted more particularly to a discussion of the total light, spectra and radial velocities of δ and ϵ Orionis. The investigations reported in the present paper include: a definitive determination of the elements of the orbit of δ Orionis from the Potsdam radial

velocity observations of Hartmann; a study of the character and a determination of the wave lengths of the measurable lines between $H\zeta$ and $H\alpha$ on 74 spectrograms of δ Orionis and 30 spectrograms of ϵ Orionis, made at the Detroit Observatory during the last three years; and studies of the radial velocities determined from these 104 spectrograms.

The principle results of this study are:

1. No certain changes are found in the spectrum of δ Orionis in a period of eleven years.

2. The wave-lengths, which were determined in this paper for all measurable lines, show interesting divergence from the assumed values, the most striking of which is that for the $H\delta$ line.

3. Some indication is found of lines of a secondary star with a mass 1.8 times that of the primary.

4. Little relation is indicated between phase and structure changes of lines in the spectrum of δ Orionis.

5. The results from least square solutions of 37 observations of δ Orionis by Hartmann at Epoch, 1902, June, and 74 observations at the Detroit Observatory at Epoch, 1913, Sept., establish no changes in the velocity curve in the interval of 11 years.

6. An improved apparent orbital period $5.732448 \pm 0.000,015$ days is derived together with other new definitive elements of the orbit of δ Orionis.

7. No certain oscillation with the broader lines is found in the case of the sharp H and K lines in δ Orionis and, using Rowland's wave-lengths, the average displacement of these sharp lines from the normal position of the oscillating lines is seven kilometers negative.

8. The D lines of sodium are seen in the spectrum of ϵ Orionis but are probably too narrow to be observed in the spectrum of δ Orionis with the dispersion employed.

9. Clear evidence of the velocity variation as announced by Frost is recognized in the Ann Arbor measures of the spectrum of ϵ Orionis. The velocity range indicated is about 11 km.

10. A provisional period of 100 days is suggested for the velocity oscillations of ϵ Orionis and shorter periods derived from this are given.

11. The conclusion is reached that the H and K lines of calcium on the Ann Arbor spectrograms of ϵ Orionis probably do not oscillate in parallel with the broader lines and are displaced negatively about nine kilometers with respect to the mean velocity for the other lines.

12. A comparison of the Ann Arbor velocities for the H and K lines with corresponding velocities determined at the Yerkes Observatory for an earlier epoch suggests a variation in the position of these lines.

13. Assuming with Hartman a calcium cloud between us and these Orion stars, the radial velocity of this medium is found to be $+ 14$ km. per second referred to the sun.

Ann Arbor, Mich., July 24, 1914.

THE SPECTRUM AND RADIAL VELOCITY OF ψ PERSEI AND OF THE BRIGHTEST COMPONENT OF β MONOCEROTIS

By PAUL W. MERRILL

The bright-line stars, ψ *Persei* and β *Monocerotis* (brightest preceding component) were placed by the writer in the ϕ *Persei* group[1] of stars of class B having bright hydrogen lines. The type star, ϕ *Persei,* is a spectroscopic binary which has been studied extensively by several observers,[1,2] and found to possess a very complex and interesting spectrum, which varies synchronously with the orbital period. The changes are, however, not exactly repeated in different revolutions. The orbit appears to be non-elliptical.

The hydrogen lines of ψ *Persei* and of β *Monocerotis* consist each of a strong, well-defined dark line flanked on either side by bright borders which are very strong at Hβ, less marked at Hγ, and at succeeding lines are so weak as to be inconspicuous or apparently absent, leaving only a sharply defined absorption line. In some cases absorption is seen outside of the bright portions. The velocities recorded in this paper as derived from the hydrogen lines depend on the central absorption, but those given by the mean of the two bright components, where measurable, are nearly the same. In other words, the emission is practically symmetrical on either side of the central dark line. 4101.98 A was taken as the wave-length of Hδ; Rowland's wave-lengths were used for the remaining hydrogen, and calcium lines. The wave-lengths for the titanium comparison lines were those determined by Mr. Mellor,[3] using the same spectrograph with which the stellar plates were secured. This is a single-prism instrument, described in Vol. I, p. 38, of these Publications.

The present observations reveal no *certain* change in any feature of the spectrum of either star. Apparent changes in the broad outside absorption of the hydrogen lines were recorded by Miss Maury.[4] Such changes might be suspected from my plates but could scarcely be established. The wide objective prism spectra probably give evidence of greater weight on this point than do slit spectrograms.[5]

The chromospheric (enhanced metallic) lines Fe 4584.10 A, and Co, Ti 4629.52 A are present in both spectra, as in ϕ *Persei,* as faint, bright-edged absorption lines. Broad and weak absorption lines of helium are present, and Mg 4481 A, of the same character. Other notes are given in the remarks following each table.

ψ PERSEI.

($\alpha = 3^h\ 29^m.4$; $\delta = +47°\ 51'$; Mag. = 4.3; Class B 5 p).

TABLE I.

DATE G.M.T.	RADIAL V.	SEPARATION Hβ	SEPARATION Hγ	RATIO
1	2	3	4	5
1911 Oct. 2.820	+0.2 km.	3.26 A		
13.722	−3.4	3.76		
18.789	−0.4	3.70		
22.738	−0.6	3.40		
27.762	−0.9	3.40	2.83 A	1.20
Nov. 25.762	+4.1	3.27	2.77	1.18
29.720	+3.5	3.36		
29.748	+4.0	3.61		

[1] *Lick Observatory Bulletins, 7,* 162, 1913.

[2] Cannon, *Jour. R. A. S. Can., 4,* 195, 1910.
Ludendorff, *A. N., 168,* 17, 1910.
Jordan, *Pub. Allegheny Obs., 3,* 31, 1913.

[3] *Publ. Observatory, Univ. of Mich., 1,* 140.

[4] *Annals H. C. O., 28,* 104, 1897.

[5] Ibid., *56,* 263, 1912.

	Dec. 5.754	−2.9	3.32	2.95	1.12
	5.767	+2.8	3.67		
1912	Oct. 12.750	−3.7	3.42		
	13.726	−0.9	3.42		
	Dec. 14.665	+1.0	3.54		
1913	Jan. 12.663	−2.5	3.62	2.66	1.36
	Oct. 9.709	0.0	3.79	2.92	1.30
	9.742	−4.7	3.49		
	11.718	−0.7	3.71		
	12.757	−1.1	3.54		
	25.755	−0.4	3.30		
	31.723	+2.3	3.31		
	Nov. 1.711	+1.4	3.50		
Mean	1912.7	−0.1±0.37	3.49±0.03	2.83±0.04	1.23±0.03

Columns three and four, headed "Separation" give the measured distance between the two bright maxima of the line indicated. Column five gives the numerical ratio of the numbers in column three to the corresponding numbers in column four.

All of the plates were taken by Curtiss (who kindly turned them over to the writer for discussion) except that on 1913 Oct. 11 by Mellor, and that on 1913 Oct. 31 by Merrill.

There is no evidence of variation in radial motion. The probable error of the velocity from a single plate is ± 1.7 km. K is an absorption line, well-defined, though not very narrow. Measured on 9 plates, it yields a velocity of + 1.6 ± 1.1 km., being accordant with that from the hydrogen lines. On several plates a weak line is seen in the position of H. On the first plate of 1911 Dec. 5 the separation of the bright portions of 4629 A was measured as 2.9 A.

β MONOCEROTIS—BRIGHTEST COMPONENT.

($\alpha = 6^h\ 24^m.0$; $\delta = -6°\ 58'$; Mag. = 4.7; Class B 3 p).

TABLE II.

DATE G.M.T.			RADIAL V. (HYDROGEN LINES)	SEPARATION Hβ	SEPARATION Hγ	RATIO
1			2	3	4	5
1913	Oct.	31.794	+22.0 km.	3.90 A		
	Nov.	16.775	+20.8	3.74		
	Dec.	14.781	+21.5	3.84		
1914	Feb.	1.680	+24.6	3.92	3.19 A	1.23
	Mar.	19.556	+21.8	4.23	2.52	1.68
	Oct.	30.916	+22.3	4.34		
	Nov.	1.802	+24.2	3.88	2.69	1.44
		1.865	+22.3	3.75		
		22.800	+21.9	4.15	2.80	1.48
		22.849	+21.3	4.00	3.07	1.30
		27.764	+23.5	3.87	2.82	1.37
Mean		1914.5	+22.4±0.25	3.97±0.04	2.85±0.07	1.42±0.04

There is no evidence of variation in radial motion. The probable error of the velocity from a single plate is ± 0.84 km. Five three-prism spectrograms taken at Lick Observatory during the years 1905 to 1912 gave a mean value of + 21.6 km. for the radial velocity.[1]

[1] *Lick Observatory Bulletins*, 7, 162, 1913.

The following table summarizes measures of additional lines on the present series of plates of *β Monocerotis.*

TABLE III.—β MONOCEROTIS.

WAVE-LENGTH	RADIAL V.	NO. OF PLATES	SEPARATION OF BRIGHT COMPS.	NO. OF PLATES
1	2	3	4	5
4584.10 Fe	+18.5	4	4.2	2
3933.82A (K)	+22.6 km.	6		
3968.62 (H)	+22.8	2		
4233.40 Fe, Cr	+20.4	3	4.2 A	1
4629.52 Co, Ti	+28.3	3		

Table IV shows mean values of the separation for several of the more important of the double bright lines in the photographic region, as measured by the writer.

TABLE IV.

SEPARATION OF BRIGHT COMPONENTS.

STAR	Hβ	Hγ	RATIO	4584 A	4629 A
1	2	3	4	5	6
φ Persei	4.1 A	3.5 A	1.2	3.8 A	4.2 A
ψ Persei	(3.2) 3.49	2.83	1.23		2.9:
β Monocerotis	(3.7) 3.97	2.85	1.42	4.2	

The figures in parentheses, and all those for *φ Persei* were obtained at Lick Observatory.

GENERAL REMARKS.

The three groups of bright-line spectra of Class B, designated by the names of the typical stars, *γ Cassiopeiae*, b^2 *Cygni*, *Electra*, seem to form a series, the progression being a decrease in strength of the bright portions of the hydrogen lines, and a strengthening, or a widening, of the central absorption. In this connection the *φ Persei* group is anomalous, having intense bright lines, and strong, wide central absorption. The features distinguishing this group from the *γ Cassiopeiae* group are the strong central absorption, the sharply cut inner edges of the bright portions, and the strength of the bright chromospheric lines. It seems probable that these features are the result of vigorous atmospheric activity, which produces more marked absorption (reversal) as well as intense bright lines. The hydrogen lines in this group resemble closely in appearance the self-reversed lines of the electric arc. Since cool or non-ionized hydrogen seems incapable of selective absorption, this may be construed as an argument for the intense conditions just referred to; so that if this group of stars is to be put in a series with the others, it should probably come first.

ANN ARBOR, FEB., 1915.

THE RADIAL VELOCITY OF MAIA

By PAUL W. MERRILL

Maia (20 Tauri; $\alpha = 3^h\ 39^m.9$; $\delta = +24°4'$; Mag. = 4.8; Class B 5) was announced as a spectroscopic binary by Adams[1] in 1904. It was on this account placed on the observing program here in the fall of 1912 by Dr. Curtiss. Since then 44 plates have been secured with the one prism spectrograph,[2] of which 40 have recently been measured by the writer. The emulsion of 33 plates is Seed 23; of 7, Red Label Lantern Slide.

Little evidence of variation in the radial motion has appeared from this series. The total range is 19.5 km., and with the exception of one plate, 16.0 km. The number of lines available for measurement is small, and although they are of fair quality, especially for this class of spectrum, they are not the best. The accuracy of the actual *measurement* may be inferred from the fact that in the repetition of measures on 7 plates the greatest divergence is 3.3 km., and the average divergence 1.7 km. But, as every line-of-sight observer realizes, this unfortunately does not represent the accuracy of the deduced radial velocity.

[1] *Ap. J.*, 19, 341, 1904.

[2] This volume, p. 37.

RADIAL VELOCITY OF MAIA.

DATE		G. M. T.	NEGATIVE BY	VELOCITY	LINES*	WT.
1912	Oct.	4.863	Mellor	+ 10.4	6	..
		5.746	Lindsay Curtiss	+ 12.6	6	..
		5.765	Lindsay	+ 3.4	4, 6	..
		5.800	Lindsay	+ 11.2	6	∴
		6.750	Curtiss	+ 11.4	5	..
		7.864	Mellor	+ 13.1	4	..
		13.793	Curtiss	+ 7.6	5	½
		16.820	Mellor	+ 1.5	4	½
		25.860	Mellor	+ 3.6	4	..
		26.785	Lindsay	+ 13.9	5, 5	..
		26.790	Lindsay	+ 9.2	5	..
		26.809	Curtiss	+ 4.3	5, 5	..
	Nov.	3.799	Curtiss	+ 2.3	4	..
		3.808	Curtiss	+ 9.6	5	..
		10.816	Curtiss	+ 2.1	4	½
		10.829	Curtiss	+ 0.4	4	..
		15.756	Mellor	— 1.7	5	..
		15.767	Mellor	— 5.6	6, 5	..
		22.811	Mellor	+ 4.9	4	..
		27.725	Mellor	+ 9.9	5	..
		29.756	Mellor	+ 7.2	4	..
		29.771	Mellor	+ 8.4	5	..
		30.693	Lindsay	+ 2.0	5, 5	..
		30.714	Lindsay	+ 1.0	4	½
	Dec.	7.582	Curtiss	+ 5.1	5	..
		8.632	Curtiss	+ 9.9	4	½
		8.656	Curtiss	+ 4.7	6	½
		14.697	Lindsay	+ 4.8	4	..
		14.709	Lindsay	+ 12.3	3	..
1913	Jan.	12.718	Curtiss	— 2.1	5, 5	..
		12.739	Curtiss	+ 5.0	5	..
		24.638	Mellor	+ 8.1	5	..
		24.658	Mellor	+ 12.1	7, 5	..
	Feb.	8.619	Curtiss	+ 6.0	5	..
		8.649	Curtiss	+ 10.6	5	..
		17.616	Mellor	+ 6.2	3	..
1914	Feb.	1.524	Merrill	+ 10.2	7	..
		1.567	Merrill	+ 5.8	6	..
		1.597	Merrill	+ 6.0	5	..
		1.622	Merrill	+ 3.4	7	..
Mean:				+ 6.41 ± 0.51.		

* Two numbers in this column indicate that the velocity is the mean of two measures.

Regarding the velocity as constant the probable error of the weighted mean is ± 0.51 km., and of a single plate ± 3.1 km. This is not much larger than would be expected from the internal agreement of the lines of one plate. A plot of the observations seems slightly to indicate a minimum about 1912 Nov. 16, with the possibility of a periodicity in the neighborhood of 55 days, but the evidence is much too weak for certainty. If such a variation exists the double amplitude of the velocity range is probably but little over 10 km. per second, and is scarcely worth attacking at present in view of the many more favorable opportunities presented to the spectroscopist. A very short period is not excluded but has small probability in view of the number and distribution of the observations. The velocity range found by Adams[3] from 7 plates is 28.3 km. Of this 26.1 km. occurs in a period of two days. If a single plate be omitted the range is reduced to 16.3 km.

Using Rowland's wave-length of 3933.825 A for calcium K, the Ann Arbor series gives a velocity from that line, from 32 plates, of + 5.4 km., which does not differ substantially from that yielded by hydrogen and other elements.

March, 1914.

[3] loc. cit.

A STUDY OF THE TITANIUM SPARK AS A COMPARISON SPECTRUM IN THE SINGLE-PRISM SPECTROGRAPH

By LEWIS L. MELLOR

INTRODUCTION.

The purpose of this investigation is to study the wave-lengths of the measurable lines of the titanium spark-spectra as photographed with the single-prism spectrograph of this Observatory, as compared with similar data obtained in the laboratory with instruments of higher dispersion. It is thus hoped to determine the relative reliability of different lines for radial velocity determinations, to adjust the wave-lengths of all measurable lines to a homogeneous system for this instrument and to establish the degree of dependence which may be assumed in connection with the quantitative use of the titanium spark comparison in spectrum investigations with spectrographs of the type here employed.

It is a well known fact that the effective wave-lengths of the lines in the spark comparison of the stellar spectrograph are modified by the blending, especially under low dispersion, of lines due not only to the element used but to impurities in the terminals and to air lines which are present in the spectrum of the spark discharge through air. The detection of the errors in wave-lengths due to these causes requires the study of all the lines available, under different conditions of exposure, to discover variations of individual lines from the laboratory positions.

OBSERVATIONS.

The spectrograph with which the plates were made for this investigation has been fully described in an earlier paper by Dr. Curtiss in this volume. The comparison spectrum employed from the first has been that of the titanium spark between terminals of approximately eighty per-cent purity, the chief impurities being iron and calcium. The metal used for these terminals was procured from Eimer and Amend. The capacity and self-induction in the spark circuit have been so adjusted as to make the continuous spectrum and air lines relatively faint. The customary ground glass mat, inserted between the two sets of spark terminals and the slit-head, diffuses the continuous spectrum of the core of the spark and renders the intensity of the lines uniform throughout their length.

Twenty-six plates, with the exception of two, were selected for measurement from our observing list of stellar spectra, and may be enumerated and classified as follows: fourteen of medium exposure, the lines in the spectrum of which are numerous and well-defined; five of about twice the medium exposure and seven of about one-half the medium exposure. The plates which are included in each set have nearly the same relative intensity, but most of them were taken under various degrees of temperature, ranging from $+1.4^\circ$ C. to $+29^\circ$ C. With the exception of one on a Red Label Lantern Slide all the spectra were photographed on Seed 23's; the exposure time for the latter plate being on the average about one minute, twice this amount being required for the former.

THE MEASURING ENGINE.

The engine used for the measurement of these plates was designed by Dr. Curtiss and constructed by Messrs. Henry and Emile Colliau in the Observatory Shop. Originally the machine was intended for measurements in two co-ordinates but it has proven equally efficient for those in one. It may be well to mention a few of its interesting features.

The box casting or engine-bed is provided with ball bearings which partially support the weight of the plate carriage and allow it to move very freely in its ways.

The micrometer head, 20 cm. in diameter, is divided into two hundred divisions, which can be easily read to a tenth of a division, so that the movement of the screw can be read to $\mu/2$. The screw is 14 mm. in diameter and approximately

17 cm. in length, with a pitch of one millimeter. Soon after the machine was assembled and adjusted the periodic error for ten revolutions of the screw was determined and found to be 6×10^{-6} of an inch per quarter revolution. Later, during the measures, a different portion of the screw was tested in the same manner as before, but no appreciable deviation from the first determination could be detected.

The revolving plate-holder, intended primarily for the measurement of position angle and the orientation of the plate, is very convenient for reversing the plate and especially so for making its final adjustment.

MATERIAL.

In 1909 Kilby[1] redetermined the wave-lengths of the arc and spark lines of titanium; and the conclusion drawn from his investigations was that no determinable shift existed between them. Accordingly all available wave-lengths, in both arc and spark, were used in obtaining for present use the laboratory values of the wave-lengths of the titanium lines measured on our plates between λ 3748 Å and λ 5064 Å. These wave lengths for the arc and spark of titanium have been tabulated by Dr. Kayser[2] as determined by the following observers: Kilby (arc and spark), Fiebig (arc), Hasselberg (arc), Exner and Haschek (arc and spark), Eder and Valenta (spark), and Lohse (spark). In this list are also included Rowland's observations referred to the solar spectrum. Further, the observations of the enhanced lines of titanium by Reese[3] and Lockyer[4] were used connectively with the above list.

It should be stated however that Kilby's results are expressed on the basis of the International system, but in astrophysical work it has been customary to reduce all observations to Rowland's standard. Thus care was taken to reduce Kilby's observations to the usual standard so that consistency in all results would be maintained. The results of the several observers are in good agreement and certainly within the limits of accuracy required for this work, particularly since our measures are for the determination of relative rather than absolute values. The mean of the observations made by the investigators named above referred to Rowland's standard are found in Table 1, column 11.

METHOD OF MEASUREMENT.

On account of the great number of lines studied, each plate was measured in two sections, the first, from λ 3748 to λ 4338, in the forenoon, and the second from λ 4338 to λ 5064, in the afternoon. Each plate was measured twice, direct and reversed, and throughout the reduction each half was treated separately. Six settings were made on each pair of lines, approaching always from the same direction with a speed as nearly constant as possible. Special care was taken in order that no change in illumination should occur during the measures.

REDUCTIONS AND TABLES.

Five lines, selected on the basis of their sharpness and proper spacing on the negative were made use of in computing two sets of constants from the Hartmann interpolation formula

$$\lambda = \lambda_0 + \frac{C}{R_0 - R}.$$

where λ_0, C, and R_0 are constants depending upon the measures, λ represents the assumed wave-lengths and R the corresponding screw readings. The values of the known quantities for three lines occurring on the first half of the plate are

λ	R
3904.960	51.1863
4078.632	64.3706
4338.082	79.9988

and those for the second half

λ	R
4338.082	80.0013
4623.280	93 2674
4981.916	106.0266

[1] *Astrophysical Journal*, 30. 243-267. 1909.

[2] *Handbüch der Spectroscopie*, 6, 674-689.

[3] Ibid., 19. 322-329. 1904.

[4] Tables of the Wave-lengths of Enhanced Lines in the *Publications of the Solar Physics Committee*. 22-25, 1906.

Substituting these values of each set independently in the above equation and solving simultaneously, we obtain

$$\lambda_0=2240.977, \qquad R_0=190.6905, \qquad C=232132.4,$$

and

$$\lambda_0=2244.017, \qquad R_0=100.6743, \qquad C=231756.6.$$

The wave-lengths corresponding to the observed screw readings may now be easily computed.

MEDIUM EXPOSED PLATES.

Measures made on the first five plates were reduced to the dispersion of the first plate, and those on the remaining nine plates to the dispersion of the first five. The mean screw readings R, derived from these fourteen plates, were used for the computation of their corresponding wave-lengths λ. It should be stated, moreover, that the mean of the prism temperatures for the first plate was $+13^\circ.7$ C, which is about the average for this Observatory.

With the method of reduction employed, errors that arise in the measurement of the first plate would probably have a disproportionately large effect upon the final results. This supposition was thoroughly tested by taking the straight means of all the previous measures of each line and reducing these mean settings to the same dispersion as above. An opportunity then presented itself for making a comparison between the two different values of R for any line and finally for obtaining the corresponding differences in wave-lengths, which on the average was approximately 0.003 Å, except in one or two instances where the lines were ill-defined. Although the second reduction showed these differences to be very small it seemed best to make use of them for the determination of the mean values of the screw readings and wave-lengths, R_m and λ_m, which are given in Table 1, columns 1 and 2. Column 3 contains the probable errors, $P.E.$, in Ångstrom units. Those lines having probable errors large enough to make them unreliable for radial velocity determinations were excluded from the final list.

TABLE I.

Rm (1)	λm (2)	P. E. (3) ±	RM (4)	λM (5)	P.E. (6) ±	λo—λm (7)	λu—λm (8)	CURTISS (9)	SCHLESINGER & BAKER (10)	ROWLAND'S STANDARD (11)	REMARKS (12)
36.6670	3748.121	0.0048	36.6660	3748.111	0.0041	—0.026				3748.181	P 1
37.1598	3752.985	0.0030	37.1592	3752.979	0.0022	—0.024	+0.006	3753.057		3753.017	G 6
37.6559	3757.879	0.0039	37.6557	3757.877	0.0033	—0.004				3757.836	F 3
37.8120	3759.428	0.0028	37.8120	3759.428	0.0021	+0.010	—0.007	3759.418		3759.449	G 9
38.0152	3761.440	0.0066	38.0160	3761.456	0.0048	+0.019	+0.001	3761.410		3761 469	G 10
39.0470	3771.782	0.0052	39 0468	3771.780	0.0045	—0.004				3771.809	P 0.3
40.4654	3786.220	0.0033	40.4655	3786.221	0.0028	+0.005		3786.188		3786.188	F 0.8
43.1900	3814.752	0.0056	43.1900	3814.752	0.0048	—0.001		3814.722		3814.723	F 0.5
48.6691	3875.441	0.0078	48.6689	3875.439	0.0067	—0.007				3875.434	F 0.5
49.2995	3882.724	0.0052	49.2999	3882.729	0.0038	±0.000	+0.010	3882.678			F 3 Br Bl(2 lines)
50.8328	3900.720	0.0054	50.8329	3900.721	0.0040	+0.009	—0.004	3900.672		3900.711	G 8
51.1864	3904.926	0.0061	51.1868	3904.931	0.0045	±0.000	+0 010	3904.942		3904.960	G 3
51.9127	3913.630	0.0054	51.9126	3913.629	0.0044		—0.002			3913.640	F 4 Br.
52.5695	3921.582	0.0036	52.5690	3921.576	0.0031	—0.016				3921.584	F 1
52.8239	3924.684	0.0052	52.8240	3924.686	0.0038	±0.000	+0.003	3924.663	.672	3924.687	G 2
53.2595	3930.015	0.0028	53.2592	3930.011	0.0024	—0.012		3930.041	.037	3930.026	G 1.5
53.4329	3932.147	0.0050	53.4331	3932.149	0.0043	+0.008				3932.188	G 1 2
54.7032	3947.946	0.0067	54.7063	3947.987	0.0055		+0.082			3947.924	G 1
54.7759	3948.857	0.0070	54.7754	3948.851	0.0057		—0.011			3948.825	G 3
55.3813	3956.498	0.0044	55.3808	3956.492	0.0032	—0.012	—0.003			3956.479	G 3

Rm (1)	λm (2)	P. E. (3) ±	RM (4)	λM (5)	P.E. (6) ±	λo—λm (7)	λu—λm (8)	CURTISS (9)	SCHLES-INGER & BAKER (10)	ROW-LAND'S STANDARD (11)	REMARKS (12)
55.5296	3958.380	0.0047	55.5294	3958.378	0.0034	—0.015	—0.015		.385	3958.366	G 3.5
55.8924	3963.004	0.0031	55.8924	3963.003	0.0023	+0.002	—0.002	3963.006	.013	3963.013	G 1.8
56.0008	3964.390	0.0038	56.0014	3964.398	0.0028	+0.017	+0.004		.408	3964.429	G 1.8
57.9676	3989.936	0.0042	57.9678	3989.939	0.0031	—0.003	+0.009	3989.885	.921	3989.930	G 7 Br.
58.6388	3998.827	0.0036	58.6389	3998.828	0.0026	—0.007	+0.008	3998.805	.820	3998.804	G 7 Br.
59.4076	4009.131	0.0046	59.4081	(4009.137)	0.0034	+0.038	—0.014	4009.109		4009.133	G 4 Br.
59.6598	4012.537	0.0048	59.6605	(4012.547)	0.0035	—0.033	+0.044		.567	4012.550	F 3
60.5617	4024.833	0.0042	60.5611	4024.824	0.0031	+0.017	—0.030			4024.733	G 5 Br.
60.6963	4026.681	0.0067	60.6915	4026.614	0.0057	+0.028				4026.691	F 1
60.8279	4028.495	0.0034	60.8282	4028.499	0.0025	+0.009	+0.002	4028.469	.512	4028.495	G 4
60.9833	4030.640	0.0039	60.9826	4030.630	0.0033	—0.026				4030.652	F 1
62.0866	4045.997	0.0053	62.0859	4045.987	0.0045	—0.028				4045.975	F 0.5 Fe 3
62.6499	4053.949	0.0043	62.6508	4053.962	0.0032	—0.013	+0.036	4053.985	.982	4053.982	G 2
62.7269	4055.042	0.0056	62.7272	4055.046	0.0048	+0.013				4055.181	F 1
63.1048	4060.420	0.0056	63.1051	4060.424	0.0048	+0.012			.412	4060.422	G 1.5
63.4097	4064.781	0.0046	63.4093	4064.774	0.0039	—0.018					F 2 Bl (2 lines)
64.3707	4078.659	0.0027	64.3704	(4078.654)	0.0020	—0.051	+0.026	4078.635	.618	4078.632	G 4
64.6431	4082.635	0.0045	64.6426	4082.627	0.0039	—0.023		4082.623		4082.609	G 2.5
66.6769	4112.845	0.0074	66.6766	4112.841	0.0063	—0.011		4112.882		4112.874	F 1.5
67.3056	4122.384	0.0063	67.3053	4122.380	0.0054	—0.012				4122.316	P 0.5
67.3859	4123.609	0.0062	67.3862	4123.614	0.0053	+0.014					F 0.8 Bl (2 lines)
67.6553	4127.797	0.0065	67.6553	4127.797	0.0056	±0.000				4127.692	F 0.8
68.2813	4137.380	0.0051	68.2816	4137.385	0.0044	+0.014				4137.437	F 1
69.1585	4151.059	0.0056	69.1585	4151.059	0.0048	—0.001					P 1
69.9690	4163.888	0.0046	69.9682	4163.876	0.0034	—0.025	—0.007	4163.829	.845	4163.829	G 8
70.4784	4172.028	0.0048	70.4786	4172.032	0.0035	—0.022	+0.023	4172.071	.063	4172.077	G 7
71.3592	4186.282	0.0048	71.3590	4186.280	0.0035	—0.007	+0.001	4186.301	.285	4186.301	G 2
73.8409	4227.591	0.0075	73.8404	4227.582	0.0064	—0.024					F 15 Fe (?)
74.4513	4238.003	0.0046	74.4516	4238.008	0.0039	+0.014		4238.031		4238.031	F 1
75.5019	4256.222	0.0080	75.5025	4256.233	0.0069	+0.031				4256.208	F 1
75.9070	4263.336	0.0056	75.9074	4263.343	0.0041	+0.006	+0.010	4263.366	.289	4263.295	G 3.5
76.5514	4274.755	0.0059	76.5525	4274.775	0.0043	+0.005	+0.036	4274.736	.763	4274.746	G 2
76.7524	4278.348	0.0052	76.7518	4278.337	0.0045	—0.032				4278.368	F 1
77.6297	4294.163	0.0067	77.6326	(4294.215)	0.0049	—0.015	+0.048		.266	4294.273	G 5
78.2786	4306.024	0.0076	78.2794	4306.039	0.0056	+0.002	+0.029			4306.081	G 5
78.3898	4308.067	0.0083	78.3880	(4308.035)	0.0061	—0.003	—0.061	4308.031		4308.068	G 4
78.7717	4315.141	0.0076	78.7711	4315.130	0.0056	—0.037	+0.005	4315.066			G 5 Bl (2 lines)
78.9698	4318.803	0.0072	78.9693	4318.795	0.0062	—0.025		4318.797		4318.818	F 2
79.3491	4325.886	0.0065	79.3491	4325.887	0.0056	+0.003					F 2 Bl (2 lines)
79.6056	4330.701	0.0072	79.6057	4330.702	0.0062	+0.004				4330.873	F 1
79.9986	4338.123	0.0099	79.9993	4338.136	0.0073	—0.002	+0.027	4338.117	.082	4338.081	G 10
80.0013	4338.142	0.0065	80.0010	4338.137	0.0048	—0.027	+0.011			4338.081	G 10
80.1800	4341.522	0.0042	80.1799	4341.521	0.0036	—0.003				4341.534	F 1
80.3319	4344.406	0.0078	80.3314	4344.398	0.0067	—0.025				4344.456	F 1
80.6784	4351.011	0.0051	80.6788	4351.018	0.0044	+0.022				4351.001	F 1
81.5489	4367.795	0.0072	81.5496	(4367.808)	0.0053	—0.049	+0.063	4367.823	.876	4367.843	F 3
81.9201	4375.019	0.0050	81.9202	4375.021	0.0043	+0.007				4374.963	F 1
82.5312	4387.050	0.0062	82.5316	4387.058	0.0053	+0.022				4387.025	F 2
83.1753	4399.882	0.0068	83.1756	4399.888	0.0050	+0.002	+0.010	4399.944	.931	4399.944	G 3
83.4069	4404.536	0.0056	83.4064	4404.526	0.0041	—0.005	—0.015			4404.486	F 2
83.7385	4411.238	0.0062	83.7382	4411.234	0.0046	+0.023	—0.025			4411.252	G 1.5
84.0593	4417.766	0.0042	84.0595	(4417.771)	0.0031	—0.037	+0.037	4417.844			G 10 Bl (2lines)
85.3312	4444.049	0.0097	85.3305	4444.033	0.0071	—0.014	—0.022	4444.026		4443.975	G 10
85.5806	4449.274	0.0097	85.5834	4449.334	0.0079		+0.120			4449.326	G 4
85.6602	4450.946	0.0090	85.6579	4450.898	0.0074		—0.095				G 4 Bl (2 lines)

Rm (1)	λm (2)	P. E. (3) ±	RM (4)	λM (5)	P.E. (6) ±	λo—λm (7)	λu—λm (8)	CURTISS (9)	SCHLESINGER & BAKER (10)	ROWLAND'S STANDARD (11)	REMARKS (12)
85.7788	4453.436	0.0069	85.7806	4453.475	0.0056		+0.078	4453.589			G 4 Bl (2 lines)
85.8732	4455.437	0.0071	85.8719	4455.411	0.0058		—0.053		.485	4455.493	G 4
85.9771	4457.632	0.0097	85.9751	4457.591	0.0079		—0.082	4457.563	.596	4457.603	G 5
86.4979	4468.709	0.0046	86.4982	4468.716	0.0034	+0.021	—0.002	4468.692	.676	4468.664	G 9
86.6102	4471.113	0.0082	86.6115	4471.140	0.0070	+0.076		4471.298			G 1 Bl (2 lines)
87.0882	4481.376	0.0097	87.0880	4481.371	0.0071	+0.003	—0.012	4481.391		4481.439	G 3.5
87.4292	4488.787	0.0095	87.4290	(4488.784)	0.0070	+0.052	—0.043				G 6 Bl (2 lines)
87.7747	4496.324	0.0068	87.7746	4496.322	0.0058	—0.005		4496.196	.319	4496.327	G 3
88.0084	4501.453	0.0073	88.0090	(4501.467)	0.0054	+0.044	—0.009	4501.423	.434	4501.449	F 10
88.5283	4512.946	0.0070	88.5272	4512.927	0.0051	—0.031	—0.016	4512.974	.909	4512.906	G 6
88.7677	4518.277	0.0055	88.7677	4518.279	0.0040	+0.026	—0.016	4518.246		4518.202	G 7
88.9770	4522.938	0.0090	88.9771	4522.940	0.0066	+0.031	—0.018	4522.961	.983	4522.981	G 7
89.1760	4527.421	0.0097	89.1767	(4527.442)	0.0071	—0.078	+0.087		.488	4527.485	G 5
89.9470	4544.902	0.0073	89.9474	4544.912	0.0054	—0.012	+0.034	4544.868	.875	4544.864	G 5
90.4144	4555.627	0.0081	90.4138	(4555.613)	0.0059	+0.053	—0.064		.576	4555.671	G 5 close line
90.7738	4563.940	0.0074	90.7741	4563.948	0.0054	+0.037	—0.011	4563.956		4563.947	G 8
91.1275	4572.179	0.0071	91.1276	4572.181	0.0052	+0.019	—0.009			4572.158	F 10
91.8898	4590.134	0.0079	91.8894	4590.124	0.0068	—0.026				4590.139	F 2
93.0282	4617.461	0.0086	93.0280	4617.457	0.0063	+0.001	+0.006	4617.457	.458	4617.440	G 8
93.2674	4623.281	0.0082	93.2673	4623.278	0.0060	+0.019	—0.019	4623.285	.264	4623.268	G 2.5
93.9396	4639.801	0.0040	93.9399	(4639.809)	0.0029	+0.043	—0.015				G 8 Bl (3 lines)
94.1608	4645.285	0.0060	94.1603	4645.274	0.0051	—0.029				4645.350	P 0.8
94.6160	4656.660	0.0108	94.6159	4656.658	0.0079	—0.018	+0.010	4656.612		4656.622	G 5
95.0571	4667.785	0.0090	95.0565	(4667.770)	0.0066	—0.055	+0.011	4667.777	.777	4667.750	F 4
95.6177	4682.078	0.0078	95.6175	4682.074	0.0057	+0.007	—0.011	4682.072	.071	4682.084	G 6
95.9818	4691.450	0.0107	95.9819	4691.453	0.0092	+0.010				4691.504	F 1.5
96.2702	4698.930	0.0065	96.2708	4698.945	0.0056	+0.040				4698.940	F 1.5
97.9324	4742.929	0.0081	97.9326	4742.933	0.0069	+0.012			.942	4742.965	F 1.5
98.5220	4758.917	0.0086	98.5217	4758.909	0.0063	—0.030	+0.005	4758.926			F 6 Bl (3 lines)
100.1920	4805.333	0.0122	100.1914	(4805.316)	0.0089	—0.083	+0.008	4805.469			G 4 Bl (2 lines)
101.4365	4841.055	0.0090	101.4359	4841.037	0.0066	—0.007	—0.031	4841.003	.075	4841.038	G 3
101.9519	4856.142	0.0119	101.9518	4856.139	0.0087	±0.000	—0.006	4856.211	.162	4856.187	F 2
102.4024	4869.475	0.0102	102.4025	4869.477	0.0088	+0.005					P 1.5 Bl (2 lines)
102.9296	4885.255	0.0099	102.9300	(4885.268)	0.0073	+0.053	—0.013	4885.257	.268	4885.249	G 1.5
103.4192	4900.077	0.0093	103.4194	4900.085	0.0054	+0.023				4900.089	G 2
106.0266	4981.933	0.0115	106.0266	4981.931	0.0084	—0.011	+0.005	4981.884		4981.916	G 5
106.3118	4991.194	0.0054	106.3118	4991.193	0.0040	—0.009	+0.004	4991.147		4991.248	G 4
106.5729	4999.728	0.0066	106.5728	4999.726	0.0048	+0.015	—0.014	4999.770		4999.683	F 4
106.8060	5007.393	0.0119	106.8054	(5007.376)	0.0087	—0.077	+0.022	5007.435		5007.391	G 4
107.0217	5014.524	0.0092	107.0217	(5014.524)	0.0068	+0.053	—0.037			5014.411	F 3.5
107.6730	5036.280	0.0119	107.6733	(5036.289)	0.0087	—0.017	+0.033				P 2 Bl (2 lines)

Lines of the greatest brightness in the spark spectrum are referred to in column 12 as having an intensity 10; other lines are given an intensity varying from 9 to 0.2, depending on their estimated brightness. The character of the lines is denoted by the letters G, F, P, Bl, and Br., signifying good, fair, poor, blend, and broad. Provisional weights, ranging from 0 to 4, were assigned to the various lines for convenience, according to their character on the negative.

The mean of the screw readings, R_o and R_u, made on the over and under exposed plates were reduced to the dispersion formerly used. Column 4 contains R_M, which represents the weighted means of the three values designated by R_m, R_o and R_u. The differences between the wave-lengths corresponding to these screw readings, of lines having weights 2, 3, and 4, and the similar values in Rowland's standard were then plotted as ordinates against their wave-lengths as

abscissae and a correction curve was drawn through these residuals. In drawing this curve those lines which showed pronounced changes in position with variation of exposure time were not taken into account. The computed wave-lengths were then corrected from the correction curve and their final values, λ_M, corresponding to their screw readings, R_M, are given in column 5. Lines which change their relative positions are enclosed in parentheses and are to be considered as unreliable. Columns 7 and 8 contain respectively, $\lambda_o - \lambda_m$ and $\lambda_u - \lambda_m$, where λ_o is the wave-length of any line determined from the over exposed plates and λ_u the corresponding wave-lengths determined from under exposures. The quantities in these two columns thus show at a glance the effect of varying exposure on the positions of the several lines. The final probable errors for lines measured on the three sets of plates are found in column 6.

In the first column, Table II, are found the screw readings for each whole turn of the screw, and the corresponding values of λ and $d\lambda/dR$ are given in the next two columns. The last two columns give the values of $dV/d\lambda$, derived by dividing the velocity of light in kilometers per second by the wave-length, and the values of dV/dR, which represent radial velocities resulting from each half turn of the screw. The results tabulated here are for future reference, in connection with work done at this Observatory.

TABLE II.

R	$\frac{d\lambda}{dR}$	λ	$\frac{dv}{d\lambda}$	$\frac{dv}{dR}$
(1)	(2)	(3)	(4)	(5)
37	9.83	3751	79.94	786
38	9.96	3761	79.73	794
39	10.09	3771	79.52	802
40	10.22	3781	79.31	811
41	10.36	3792	79.08	819
42	10.50	3802	78.87	828
43	10.64	3813	78.64	837
44	10.79	3824	78.42	846
45	10.94	3834	78.21	856
46	11.09	3845	77.99	865
47	11.24	3857	77.74	874
48	11.40	3868	77.52	884
49	11.56	3879	77.30	894
50	11.73	3891	77.07	904
51	11.90	3903	76.83	914
52	12.07	3915	76.59	924
53	12.24	3927	76.36	935
54	12.42	3939	76.13	946
55	12.61	3952	75.88	957
56	12.80	3964	75.65	968
57	12.99	3977	75.40	979
58	13.18	3990	75.15	990
59	13.38	4004	74.89	1002
60	13.59	4017	74.65	1014
61	13.80	4031	74.39	1027
62	14.02	4045	74.13	1039
63	14.24	4059	73.88	1052
64	14.46	4073	73.62	1065
65	14.69	4088	73.35	1078
66	14.93	4103	73.08	1091
67	15.17	4118	72.82	1105
68	15.42	4133	72.55	1119
69	15.68	4149	72.27	1133
70	15.94	4164	72.01	1148
71	16.20	4180	71.73	1162
72	16.48	4197	71.45	1177
73	16.76	4213	71.17	1193
74	17.05	4230	70.89	1209
75	17.34	4248	70.59	1224
76	17.65	4265	70.31	1241
77	17.96	4283	70.01	1257
78	18.28	4301	69.72	1274
79	18.61	4319	69.43	1293
80	18.92	4338	69.12	1308
81	10.27	4357	68.82	1326
82	19.63	4377	68.51	1345
83	19.99	4397	68.20	1363
84	20.37	4417	67.89	1383
85	20.76	4437	67.58	1403
86	21.15	4458	67.26	1423
87	21.56	4480	66.93	1443
88	21.99	4501	66.62	1465
89	22.42	4524	66.28	1486
90	22.87	4546	65.96	1509
91	23.33	4569	65.63	1531
92	23.80	4593	65.29	1554
93	24.30	4617	64.95	1578
94	24.80	4641	64.61	1602
95	25.32	4667	64.25	1627
96	25.86	4692	63.91	1653
97	26.41	4718	63.56	1679
98	26.99	4745	63.19	1705
99	27.58	4772	62.84	1733
100	28.19	4800	62.47	1761
101	28.82	4829	62.10	1790
102	29.48	4858	61.72	1820
103	30.15	4888	61.35	1850
104	30.85	4918	60.97	1881
105	31.58	4949	60.59	1913
106	32.33	4981	60.20	1946
107	33.10	5014	59.80	1979
108	33.91	5047	59.41	2015

PARALLEL RESULTS.

Ten plates by Curtiss and eight plates by Schlesinger and Baker,[5] made with the Mellon spectrograph of Allegheny Observatory, were reduced separately so as to conform to the above results. The final wave-lengths of the lines measured on these two sets of plates are given in Table 1, columns 9 and 10. The lines whose computed wave-lengths differ by more than 0.1 Å from Rowland's standard are λ 3947, λ 4330, λ 4344, λ 4455, and λ 4555. The wave-lengths of the two adjacent lines λ 4555 and λ 4552 are respectively 0.22 and 0.11 less than the laboratory wave-lengths. The latter line was not included in the table for reasons stated above. Schlesinger and Baker found the differences for these two lines to be respectively 0.09 and 0.11.

[5] *Publications of the Allegheny Observatory*, 1, No. 2, 9-17.

CONCLUSION.

The conclusion drawn from this investigation is that certain lines in the titanium comparison spectrum change their relative positions with variation of exposure time. This displacement is probably due, excepting in the case of titanium lines which naturally blend under low dispersion, to the presence of air lines, although they appear to be comparatively faint. More self-induction may be introduced into the electrical circuit to reduce the relative brightness of the air lines. There could be no objection to such a change since laboratory investigations under high dispersion indicate that the variation of the wave-lengths caused by this alteration in the condition of the spark circuit is too small to affect the work of this instrument. But in any case it would seem advisable to employ those comparison lines which were found to be unaffected by variation of exposure time.

I wish to express my thanks to Dr. Curtiss, whose kindly interest and criticism have been of great importance throughout this investigation.

August, 1913.

OBSERVATIONS OF DOUBLE STARS DISCOVERED AT LA PLATA

THIRTEENTH CATALOGUE

By W. J. HUSSEY

The search which has yielded the new double stars of this Catalogue is an extension of the survey of the northern sky, which was begun by me at the Lick Observatory early in the spring of 1899, and afterward independently by Professor Aitken. This survey was conducted jointly by us, with a zonal division of the sky, from July, 1899, when we each first learned that the other had begun such work, until 1905, when I returned to the University of Michigan. Professor Aitken has continued the work since that time and with more than 2,700 discoveries to his credit he has now nearly completed the survey of the northern sky. And by reason of my connection with the University of La Plata I have been able to commence the examination of the southern stars.

This systematic search for new double stars, which has now resulted in more than four thousand discoveries, had its inception, so far as I am concerned, in a suggestion respecting the need of such work, made by Professor Keeler, in June, 1898, at the time he assumed his duties as Director of the Lick Observatory, and again later in the same year, when in connection with the work which I was doing on the double stars of the Pulkowa Catalogue, new components to a few of the Otto Struve double stars and occasional new pairs in the vicinity of these were found.

The double stars of the present Catalogue were discovered with the 17-inch refractor of the La Plata Observatory, mostly during the latter part of 1911. No micrometer was then available for measuring position angles and distances with this telescope, but it was expected that one would be fitted to it in a few months and that measurements could then be made of the new pairs which were being found. After my return to La Plata in July, 1912, however, my time was so taken with other duties that I was not able to give much attention to this work and consequently many pairs are still unmeasured. In order not to delay the announcement of these discoveries too long some are included in this list with the rough estimates only of position angle and distance which were made at the time of discovery.

The numbers assigned to the double stars of this Catalogue are in continuation of those given in my earlier catalogues of new double stars, printed in *The Astronomical Journal,* Nos. 480, 485, 494, and in the *Bulletins of the Lick Observatory,* Nos. 12, 21, 27, 57, 65, 74, 77, 81, 117. The number of double stars announced in these twelve catalogues is 1337. While at the Lick Observatory I suspected a faint and comparatively close companion to the principal component of Σ 1448, whose existence has since been verified by Professor Aitken with the large refractor of the Lick Observatory. His measures of it are given in *Lick Observatory Bulletin,* No. 184, with the designation, Hu. 1338. Accordingly the present list begins with Hu. 1339 and continues to Hu. 1550. A number of additional pairs have been found at La Plata, which will be published in a subsequent list.

The right ascensions and declinations given below are for the epoch 1875. They have been taken from the *Cape Photographic Durchmusterung.* The sidereal time of observation and the power used are given in the last two columns.

Hu. 1339. C.P.D. —54° 19

R.A. $0^h\ 2^m\ 43^s$; Decl. —54° 41′.8.

(7.5 . . . 8.5)

1913.787	284°.7	0.″39	$22^h.1$	670

Hu. 1340. C.P.D. —48° 76

R.A. $0^h\ 37^m\ 46^s$; Decl. —48° 34′.1

(8 8 . . . 9.5)

1913.718	211.2	1.57	22.6	670
.819	213.2	1.62	5.0	400
1913.77	212.2	1.60		

Hu. 1341. C.P.D. —45° 112

R.A. $0^h\ 55^m\ 30^s$; Decl. —45° 58′.5

(9.0 . . . 10.5) nf. 2″

Hu. 1342. C.P.D. — 57° 251

R.A. 1ʰ 4ᵐ 9ˢ; Decl. — 57° 15′.7
(7.0 . . . 7.5)

1913.819	348.1	0.33	5.9	670

Hu. 1343. C.P.D. — 46° 121

R.A. 1ʰ 6ᵐ 1ˢ; Decl. — 46° 7′.8
(8.5 . . . 8.8)

1913.718	252.8	3.60	23.0	300

Hu. 1344. C.P.D. — 47° 174

R.A. 1ʰ 25ᵐ 51ˢ; Decl. — 47° 2′.2
(8.8 . . . 9.2)

1913.718	103.0	1.55	23.3	300

Hu. 1345. C.P.D. — 57° 330

R.A. 1ʰ 29ᵐ 30ˢ; Decl. — 57° 38′.5
(6.5 . . . 12.0)

1913.787	201.0	5.42	23.3	300

Hu. 1346. C.P.D. — 45° 189

R.A. 1ʰ 35ᵐ 10ˢ; Decl. — 45° 40′.2
(8.5 . . . 10.5) nf. 5″

Hu. 1347. C.P.D. — 48° 245

R.A. 2ʰ 1ᵐ 53ˢ; Decl. — 48° 24′.0
(9.0 . . . 9.5)

1913.718	320.0	0.83	23.7	300

Hu. 1348. C.P.D. — 57° 448

R.A. 2ʰ 23ᵐ 33ˢ; Decl. — 57° 18′.0
(10 . . . 10) 120° 0″.5

Hu. 1349. C.P.D. — 48° 286

R.A. 2ʰ 27ᵐ 11ˢ; Decl. — 48° 54′.3
(9.0 . . . 10.5)

1913.718	332.8	8.85	0.1	300

Hu. 1350. C.P.D. — 54° 464

R.A. 2ʰ 35ᵐ 43ˢ; Decl. — 54° 57′.2
(8.8 . . . 10.0) 210° 0″.5

Hu. 1351. C.P.D. — 48° 311

R.A. 2ʰ 46ᵐ 7ˢ; Decl. — 48° 37′.3
(9.0 . . . 9.0)

1913.718	108.6	1.42	0.3	300

Hu. 1352. C.P.D. — 56° 478

R.A. 2ʰ 53ᵐ 34ˢ; Decl. — 56° 43′.1
(9.5 . . . 10.0) 185° 1″.5

Hu. 1353. C.P.D. — 56° 506

R.A. 3ʰ 10ᵐ 24ˢ; Decl. — 56° 31′.8
(9.5 . . . 11.5)

1913.787	190.6	2.59	0.5	300

Hu. 1354. C.P.D. — 43° 351

R.A. 3ʰ 12ᵐ 54ˢ; Decl. — 43° 52′.0
(8.4 . . . 13.0)

1912.853	161.4	2.08	...	300
.856	160.7	2.21	1.3	300
.859	161.8	2.20	0.4	300
1912.86	161.3	2.16		

Hu. 1355. C.P.D. — 45° 328

R.A. 3ʰ 15ᵐ 14ˢ; Decl. — 45° 33′.7
(8.4 . . . 12.0)

1912.853	314.4	1.45	0.8	300
.916	314.3	1.57	1.2	300
1912.88	314.4	1.51		

A neighboring pair was measured as follows:

1912.859	287.6	5.06	0.7	300

Magnitudes: 9.5 . . . 9.8

Hu. 1356. C.P.D. — 45° 339

R.A. 3ʰ 20ᵐ 39ˢ; Decl. — 45° 31′.0
(9.5 . . . 10.5)

1912.853	181.4	1.40	1.0	300
.859	182.5	1.44	0.9	300
.916	183.5	1.54	1.2	300
1912.87	182.5	1.46		

Hu. 1357. C.P.D. — 55° 527

R.A. 3ʰ 23ᵐ 32ˢ; Decl. — 55° 54′.2
(8.0 . . . 8.2)

1913.787	20.8	1.35	0.9	300

Hu. 1358. C.P.D. — 49° 436

R.A. 3ʰ 34ᵐ 16ˢ; Decl. — 49° 13′.4
(8.5 . . . 11.0) 280° 4″

Hu. 1359. C.P.D. — 47° 382

R.A. 3ʰ 43ᵐ 49ˢ; Decl. — 47° 23′.9
(9.3 . . . 9.3) 130° 0″.8

Hu. 1360. C.P.D. — 42° 378

R.A. 3ʰ 52ᵐ 15ˢ; Decl. — 42° 59′.4
(9.2 . . . 9.8)

1912.853	39.1	1.59	1.2	300
.856	36.1	1.62	1.8	300
.859	36.6	1.83	1.1	300
1912.86	37.3	1.68		

Hu. 1361. C.P.D. —48° 418

R.A. 3h 52m 21s; Decl. —48° 8′.0
(7.7 . . . 11.2)

1912.894	83.0	4.33	1.3	300
.897	82.5	4.11	1.1	300
1912.90	82.8	4.22		

Hu. 1362. C.P.D. —48° 437

R.A. 4h 00m 02s; Decl. —48° 5′.2
(9.5 . . . 10.5)

1912.894	65.0	2.11	1.4	300
.897	62.6	1.96	1.2	300
1912.90	63.8	2.04		

Hu. 1363. C.P.D. —22° 458

R.A. 4h 01m 33s; Decl. —22° 19′.7
(7.5 . . . 7.5) . . . 0″.3

Hu. 1364. C.P.D. —54° 626

R.A. 4h 3m 53s; Decl. —54° 19′.7
(9.2 . . . 11.5)

1912.877	83.9	5.00	0.9	300
1913.787	84.7	5.17	1.3	300
1913.33	84.3	5.08		

Hu. 1365. C.P.D. —44° 455

R.A. 4h 12m 48s; Decl. —44° 36′.0
(9.0 . . . 9.5)

1912.853	340.6	1.93	1.4	300
.856	341.0	1.94	2.2	300
.859	343.0	1.96	1.2	300
1912.86	341.5	1.94		

Hu. 1366. C.P.D. —30° 573

R.A. 4h 12m 59s; Decl. —30° 10′.5
(9.3 . . . 11.0) 260° 2″

Hu. 1367. C.P.D. —48° 488

R.A. 4h 19m 8s; Decl. —48° 11′.5
(9.3 . . . 9.3) 260° 0″.8

Hu. 1368. C.P.D. —54° 658

R.A. 4h 20m 45s; Decl. —54° 8′.4
(9.2 . . . 9.5)

1912.877	56.6	2.26	1.3	300
1913.787	56.1	2.28	1.4	300
1913.33	56.4	2.27		

Hu. 1369. C.P.D. —29° 572

R.A. 4h 20m 49s; Decl. —29° 2′.3
(9.0 . . . 9.5) 330° 0″.5

Hu. 1370. C.P.D. —56° 679

R.A. 4h 24m 54s; Decl. —56° 11′.0
(8.8 . . . 9.5)

1912.877	139.4	6.76	1.6	300
.951	138.7	6.54	2.7	300
1913.787	139.6	6.59	1.6	300
1913.20	139.2	6.63		

Hu. 1371. C.P.D. —31° 560

R.A. 4h 28m 13s; Decl. —31° 23′.3
(8.8 . . . 8.8) . . . 0″.7

Hu. 1372. C.P.D. —42° 492

R.A. 4h 28m 31s; Decl. —42° 46′.3
(9.2 . . . 9.8)

1912.853	280.1	3.90	1.8	300
.856	281.4	3.97	2.3	300
.859	280.2	3.73	. . . .	300
1912.86	280.6	3.87		

Hu. 1373. C.P.D. —55° 666

R.A. 4h 32m 1s; Decl. —55° 17′.6
(9.2 . . . 9.8)

1912.877	80.1	1.15	1.8	300

Hu. 1374. C.P.D. —24° 691

R.A. 4h 37m 58s; Decl. —24° 44′.3
(9.0 . . . 10.0) 90° 0″.7

Hu. 1375. C.P.D. —55° 685

R.A. 4h 39m 19s; Decl. —55° 02′.2
(8.0 . . . 12.0)

1912.877	179.5	4.06	1.9	300
.932	183.4	3.46	2.9	300
.938	182.5	3.90	2.0	300
.943	180.2	3.62	2.9	300
1912.92	181.4	3.76		

Hu. 1376. C.P.D. —44° 527

R.A. 4h 42m 06s; Decl. —44° 30′.7
(8.5 . . . 10.5)

1912.853	314.8	5.37	2.2	300
.856	315.8	5.42	2.6	300
.859	315.5	5.51	. . . .	300
1912.86	315.4	5.43		

Hu. 1377. C.P.D. — 44° 536

R.A. 4^h 43^m 55^s; Decl. — 44° 35′.9
(10.0 . . . 10.5)

1912.853	325.4	6.02	2.4	300
.856	325.8	5.90	2.7	300
.859	325.3	6.07	....	300
1912.86	325.5	6.00		

Hu. 1378. C.P.D. — 42° 534

R.A. 4^h 43^m 58^s; Decl. — 42° 06′.6
(9.0 . . . 10.0)

1912.859	273.0	0.98	1.6	300
.916	272.9	1.33	1.8	300
.919	272.9	1.25	2.2	300
1912.90	272.9	1.19		

Hu. 1379. C.P.D. — 57° 707

R.A. 4^h 48^m 00^s; Decl. — 57° 56′.8
(8.5 . . . 9.0) 300° 0″.7

Hu. 1380. C.P.D. — 33° 621

R.A. 4^h 48^m 06^s; Decl. — 33° 18′.5
(8.5 . . . 10.5) 240° 2″

Hu. 1381. C.P.D. — 32° 635

R.A. 4^h 49^m 19^s; Decl. — 32° 12′.4
(8.5 . . . 11.0) 300° 2″

Hu. 1382. C.P.D. — 31° 664

R.A. 4^h 53^m 54^s; Decl. — 31° 50′.0
(8.5 . . . 10.0) 20° 1″

Hu. 1383. C.P.D. — 55° 722

R.A. 4^h 55^m 20^s; Decl — 55° 42′.1
(8.5 . . . 11.0)

1912.877	2.9	3.31	2.4	300
.932	6.5	3.08	2.5	300
.935	6.6	3.23	2.6	300
1912.91	5.3	3.21		

Hu. 1384. C.P.D. — 43° 530

R.A. 4^h 56^m 00^s; Decl. — 43° 30′.4
(9.2 . . . 11.5)

1912.853	339.7	4.78	2.5	300
.856	338.8	4.73	2.8	300
.859	341.5	5.01	....	300
1912.86	340.0	4.84		

Hu. 1385. C.P.D. — 23° 676

R.A. 4^h 57^m 03^s; Decl. — 23° 54′.8
(9.5 . . . 9.5) .... 1″.5

Hu. 1386. C.P.D. — 45° 570

R.A. 5^h 04^m 04^s; Decl. — 45° 55′.8
(8.5 . . . 12.0)

1913.859	53.1	7.96	2.1	300
.916	52.9	7.84	2.2	300
1913.87	53.0	7.90		

Hu. 1387. C.P.D. — 42° 608

R.A. 5^h 4^m 22^s; Decl. — 42° 32′.5
(9.0 . . . 10.0)

1912.916	238.4	0.91	2.0	300

Hu. 1388. C.P.D. — 49° 658

R.A. 5^h 6^m 33^s; Decl. — 49° 30′.4
(9.0 . . . 9.0)

1912.845	98.5	0.93	....	300

Hu. 1389. C.P.D. — 31° 740

R.A. 5^h 11^m 28^s; Decl. — 31° 05′.5
(8.0 . . . 8.5) 130° 1″

Hu. 1390. C.P.D. — 55° 772

R.A. 5^h 13^m 8^s; Decl. — 55° 21′.9
(9.0 . . . 9.5)

1912.877	137.0	1.67	2.8	300
.932	136.6	1.99	3.5	300
.935	136.1	1.71	3.0	300
1912.91	136.6	1.77		

Hu. 1391. C.P.D. — 55° 787

R.A. 5^h 15^m 42^s; Decl. — 55° 50′.3
(8.8 . . . 10.2)

1912.877	201.2	2.30	2.9	300
.932	198.8	2.18	3.3	300
.935	199.7	2.30	3.2	300
1912.91	199.9	2.26		

Hu. 1392. C.P.D. — 44° 595

R.A. 5^h 21^m 21^s; Decl. — 44° 35′.9
(8.8 . . . 11.5)

1912.856	21.8	3.80	3.1	300

Hu. 1393. C.P.D. — 33° 852

R.A. 5^h 30^m 52^s; Decl. — 33° 21′.1
(7.0 . . . 7.0) ... 0″.3

Hu. 1394. C.P.D. — 42° 709

R.A. 5^h 33^m 22^s; Decl. — 42° 47′.5
(8.8 . . . 11.0)

1912.856	120.4	4.07	3.4	300
.859	119.6	3.94	....	300
1912.86	120.0	4.00		

Hu. 1395. C.P.D. — 56° 949

R.A. 5^h 48^m 01^s; Decl. — 56° 50′.1
(8.5 . . . 9.0)

1912.877	55.6	1.05	3.7	300
.932	54.0	0.86	4.0	300
.935	57.1	1.06	3.6	300
1912.91	55.6	0.99		

Hu. 1396. C.P.D. — 30° 1071

R.A. 5^h 49^m 00^s; Decl — 30° 42′.1
(8.6 . . . 10.0) 140° 2″

Hu. 1397. C.P.D. — 44° 744

R.A. 5^h 50^m 35^s; Decl. — 44° 41′.4
(9.0 . . . 10.0)

1912.856	90.8	3.20	3.7	300
.859	91.8	3.33	. . .	300
.916	88.7	3.38	2.6	300
1912.89	90.4	3.30		

Hu. 1398. C.P.D. — 41° 853

R.A. 5^h 53^m 11^s; Decl. — 41° 46′.2
(8.0 . . . 8.5)

1912.856	212.5	1.91	3.8	300
.859	215.5	1.69	. . .	300
.916	214.0	1.86	2.7	300
1912.88	214.0	1.82		

Hu. 1399. C.P.D. — 31° 976

R.A. 5^h 55^m 40^s; Decl. — 31° 03′.0
(9.0 . . . 9.5) 340° 0″.8
Companion of Cordoba General Catalogue pair.

Hu. 1400. C.P.D. — 54° 936

R.A. 5^h 57^m 16^s; Decl. — 54° 37′.3
(8.5 . . . 9.8)

1912.877	13.6	2.45	3.4	300
.924	13.4	2.08	2.3	300
.932	14.6	2.31	4.3	300
1912.91	13.9	2.28		

Hu. 1401. C.P.D. — 56° 982

R.A. 5^h 57^m 20^s; Decl. — 56° 38′.2
(8.8 . . . 11.5)

1912.877	212.7	4.97	3.5	300
.932	213.0	5.07	4.1	300
.935	213.7	5.09	3.7	300
1912.91	213.1	5.04		

Hu. 1402. C.P.D. — 55° 921

R.A. 5^h 57^m 36^s; Decl. — 55° 13′.4
(8.7 . . . 9.8)

1912.877	294.4	1.23	3.3	300
.932	294.8	1.22	4.3	300
.935	295.6	1.27	3.9	300
1912.91	294.9	1.24		

Hu. 1403. C.P.D. — 48° 767

R.A. 5^h 58^m 42^s; Decl. — 48° 56′.1
(9.0 . . . 9.3)

1912.845	91.8	1.18	2.8	300
1913.241	90.8	1.37	9.1	300
.244	88.8	1.28	8.7	300
1913.11	90.5	1.28		

Hu. 1404. C.P.D. — 54° 950

R.A. 6^h 00^m 5^s; Decl. — 54° 21′.8
(9.0 . . . 10.0)

1912.877	184.6	0.95	3.8	300
.932	188.1	0.78	4.5	300
.935	185.0	1.15	4.1	300
.938	187.1	1.01	3.3	300
1912.92	186.2	0.97		

Hu. 1405. C.P.D. — 43° 783

R.A. 6^h 10^m 17^s; Decl. — 43° 06′.1
(9.5 . . . 10.0)

1912.916	211.8	2.43	3.2	300
1913.244	208.0	2.45	10.0	300
1913.08	209.9	2.44		

Hu. 1406. C.P.D. — 56° 1043

R.A. 6^h 13^m 10^s; Decl. 56° 6′.8
(9.0 . . . 11.5)

1912.877	189.8	2.37	4.2	300
.935	187.7	2.48	4.2	300
.938	187.5	2.37	3.5	300
1912.92	188.3	2.41		

Hu. 1407. C.P.D. — 57° 973

R.A. 6^h 13^m 21^s; Decl. — 57° 00′.8
(8.5 . . . 11.2)

1912.877	77.1	2.69	4.1	300
.935	79.3	2.45	4.4	300
.938	76.7	2.89	3.7	300
1912.92	77.7	2.68		

Hu. 1408. C.P.D. —42° 890

R.A. 6h 15m 29s; Decl. —42° 25′.9
(8.8 . . . 9.0)

1912.900	6.4	0.54	3.8	300
.916	8.4	0.58	3.3	300
1913.244	13.4	0.42	10.2	670
1913.02	9.4	0.51		

Hu. 1409. C.P.D. —56° 1059

R.A. 6h 17m 11s; Decl. —56° 30′.8
(9.0 . . . 12.0)

1912.877	201.1	1.89	4.5	300
.938	201.9	2.17	3.8	300
1912.91	201.5	2.02		

Hu. 1410. C.P.D. —46° 817

R.A. 6h 20m 50s; Decl. —46° 52′.2
(8.6 . . . 12.5)

1912.845	315.8	6.59	3.4	300
.919	319.1	6.23	3.6	300
1913.241	316.2	6.64	9.4	300
1913.00	317.0	6.49		

Hu. 1411. C.P.D. —55° 998

R.A. 6h 23m 18s; Decl. —55° 5′.3
(9.2 . . . 9.2) 130° 0″.5

Hu. 1412. C.P.D. —44° 916

R.A. 6h 24m 32s; Decl. —44° 42′.8
(8.8 . . . 12.5)

1912.856	263.4	3.88	4.0	300
.916	263.0	3.72	3.6	300
1912.89	263.2	3.80		

Hu. 1413. C.P.D. —44° 917

R.A. 6h 24m 54s; Decl. —44° 15′.9
(8.8 . . . 12.0)

1912.856	29.8	1.39	4.2	300
.900	29.5	1.47	4.0	300
.916	29.1	1.44	3.5	300
1913.244	29.5	1.42	10.9	670
1912.98	29.5	1.43		

Hu. 1414. C.P.D. —42° 981

R.A. 6h 32m 24s; Decl. —42° 31′.6
(9.2 . . . 9.2)

1912.916	97.0	0.54	3.9	300
1913.244	96.1	0.44	10.5	670
1913.08	96.6	0.49		

Hu. 1415. C.P.D. —44° 1018

R.A. 6h 33m 5s; Decl. —44° 57′.3
(7.6 . . . 12.0)

1912.900	28.9	2.01	4.3	300
.916	32.6	1.82	3.8	300
1913.244	26.7	1.89	10.6	670
1913.02	29.4	1.91		

Principal component of h 3882.

h 3882

1912.900	331.0	7.92	4.4	300

Hu. 1416. C.P.D. —42° 1051

R.A. 6h 41m 40s; Decl. —42° 24′.1
(8.6 . . . 10.0)

1912.900	82.6	1.27	4.6	300
.916	85.6	1.18	4.1	300
1913.244	88.0	1.05	11.1	300
1913.02	85.4	1.17		

Hu. 1417. C.P.D. 1103.

R.A. 6h 51m 00s; Decl. —45° 44′.1
(8.4 . . . 9.2)

1912.856	142.0	1.32	4.8	300
.900	145.9	1.59	4.8	300
.916	143.6	1.28	4.2	300
1912.87	143.8	1.40		

Hu. 1418. C.P.D. —45° 1175

R.A. 6h 59m 13s; Decl. —45° 34′.0
(8.0 . . . 10.5)

1912.856	338.6	2.55	4.9	300
.900	338.4	2.51	4.9	300
.916	341.8	2.65	4.4	300
1912.89	339.6	2.57		

Hu. 1419. C.P.D. —44° 1254

R.A. 7h 00m 12s; Decl. —44° 28′.5
(8.5 . . . 13.5)

1912.916	304.8	3.41	4.6	300
1913.244	308.8	2.94	11.3	300
1913.08	306.8	3.18		

Hu. 1420. C.P.D. —43° 1209

R.A. 7h 02m 59s; Decl. —43° 57′.1
(9.5 . . . 10.0) 190° 1″

Hu. 1421. C.P.D. — 55° 1162

R.A. 7h 05m 41s; Decl. — 55° 12′.1

(9.5 . . . 9.8)

1912.938	31.3	5.88	4.5	300
.951	29.8	5.88	4.1	300
1912.94	30.6	5.88		

Hu. 1422. C.P.D. — 42° 1364

R.A. 7h 20m 19s; Decl. — 42° 27′.6

(9.2 . . . 9.8)

1912.900	245.0	1.86	5.4	300

Hu. 1423. C.P.D. — 43° 1445

R.A. 7h 21m 7s; Decl. — 43° 8′.4

(8.0 . . . 11.5)

1912.900	298.8	5.88	5.3	300
.916	299.9	6.05	5.3	300
1912.91	299.4	5.97		

Hu. 1424. C.P.D. — 48° 1188

R.A. 7h 25m 34s; Decl. — 48° 11′.7

(9.0 . . . 9.5)

1912.897	18.4	1.23	4.8	300
.919	18.4	1.33	5.4	300
1913.241	17.4	1.49	9.9	670
1913.02	18.1	1.35		

Hu. 1425. C.P.D. — 55° 1245

R.A. 7h 25m 41s; Decl. — 55° 23′.1

(9.0 . . . 9.5)

1912.877	152.3	5.17	4.9	300
.935	151.5	5.19	4.9	300
1912.91	151.9	5.18		

Hu. 1426. C.P.D. — 42° 1577

R.A. 7h 40m 11s; Decl. — 42° 43′.1

(9.5 . . . 10.5) 210° 1″.5

Hu. 1427. C.P.D. — 44° 1851

R.A. 7h 41m 02s; Decl. — 44° 47′.8

(9.2 . . . 9.5) 255° 4″

Hu. 1428. C.P.D. — 46° 1757

R.A. 7h 43m 01s; Decl. — 46° 29′.6

(7.5 . . . 8.8)

1913.241	354.2	0.35	10.2	670
.244	353.7	0.46	9.3	670
1913.24	354.0	0.40		

Hu. 1429. C.P.D. — 43° 1784

R.A. 7h 43m 08s; Decl. — 43° 05′.2

(8.0 . . . 8.5) 310° 0″.5

Hu. 1430. C.P.D. — 43° 1936

R.A. 7h 51m 34s; Decl. — 43° 26′.9

(8.3 . . . 12.0) 142° 5″

Hu. 1431. C.P.D. — 45° 1897

R.A. 7h 52m 56s; Decl. — 45° 42′.8

(9.0 . . . 9.0) . . . 0″.3

Hu. 1432. C.P.D. — 46° 1983

R. A. 7h 55m 59s; Decl. — 46° 57′.7

(8.0 . . . 8.0)

1913.244	150.3	0.47	9.5	670

Principal Component of h 4032.

Hu. 1433. C.P.D. — 47° 1818

R.A. 8h 00m 33s; Decl. — 47° 26′.0

(9.0 . . . 10.0)

1913.244	44.1	2.45	9.6	300

Hu. 1434. C.P.D. — 57° 1393

R.A. 8h 02m 19s; Decl. — 57° 25′.3

(8.2 . . . 13.0) 315° 5″

Hu. 1435. C.P.D. — 54° 1574

R.A. 8h 14m 9s; Decl. — 54° 44′.0

(9.0 . . . 11.0)

1913.028	160.9	3.04	4.9	300
.151	160.0	3.29	6.7	300
1913.09	160.5	3.17		

Hu. 1436. C.P.D. — 57° 1463

R.A. 8h 14m 12s; Decl. — 57° 14′.3

(9.0 . . . 11.0) 120° 5″

Hu. 1437. C.P.D. — 54° 1611

R.A. 8h 19m 13s; Decl. — 54° 49′.3

(9.0 . . . 10.0)

1913.028	76.5	2.50	5.2	300
.151	74.6	2.50	6.8	300
1913.09	75.5	2.50		

Hu. 1438. C.P.D. — 55° 1544

R.A. 8h 22m 15s; Decl. — 55° 20′.4

(7.4 . . . 12.0) 200° 6″

Hu. 1439. C.P.D. —42° 2591

R.A. 8^h 26^m 1^s; Decl. —42° 45′.3
(8.6 . . . 11.0)

1913.028	121.9	3.09	6.0	300
.034	120.5	3.38	5.4	300
.088	122.3	3.19	5.3	300
1913.05	121.6	3.22		

Hu. 1440. C.P.D. —43° 2770

R.A. 8^h 30^m 55^s; Decl. —44° 47′.8
(8.5 . . . 10.0)

1913.017	181.1	1.25	6.7	300
.028	182.1	1.39	6.1	300
.034	180.1	1.18	5.8	300
1913.03	181.1	1.27		

Hu. 1441. C.P.D. —44° 2817

R.A. 8^h 32^m 46^s; Decl. —44° 51′.2
(8.8 . . . 10.0)

1913.034	33.5	1.18	6.0	300
.088	31.5	1.42	5.5	300
1913.06	32.5	1.30		

Hu. 1442. C.P.D. —43° 2874

R.A. 8^h 37^m 16^s; Decl. —43° 48′.4
(9.0 . . . 9.5)

1913.017	161.4	1.23	6.8	300
.028	164.1	1.39	6.2	300
.034	162.7	1.40	6.3	300
1913.03	162.7	1.34		

Hu. 1443. C.P.D. —55° 1674

R.A. 8^h 37^m 34^s; Decl. —55° 43′.3
(8.0 . . . 8.5)

1913.107	262.2	0.60	6.2	300
.151	258.5	0.66	7.0	300
1913.13	260.4	0.63		

Hu. 1444. C.P.D. —55° 1699

R.A. 8^h 40^m 00^s; Decl. —55° 54′.7
(9.0 . . . 10.5)

1913.107	34.8	4.41	6.3	300
.151	33.5	4.33	7.1	300
1913.13	34.2	4.37		

Hu. 1445. C.P.D. —46° 2966

R.A. 8^h 42^m 2^s; Decl. —46° 56′.3
(8.5 . . . 10.0) 190° 1″.2

Hu. 1446. C.P.D. —46° 2996

R.A. 8^h 42^m 52^s; Decl. —46° 40′.7
(9.0 . . . 9.0) 30° 3″

Hu. 1447. C.P.D. —44° 3143

R.A. 8^h 45^m 57^s; Decl. —44° 15′.3
(8.4 . . . 12.2)

1913.020	220.8	3.36	5.7	300
.088	219.8	3.48	6.0	300
1913.05	220.3	3.42		

Hu. 1448. C.P.D. —55° 1788

R.A. 8^h 46^m 09^s; Decl. —55° 41′.6
(8.4 . . . 11.0)

1913.107	323.2	2.43	5.8	300
.151	326.1	2.72	7.4	300
.157	324.8	2.48	6.5	300
1913.14	324.7	2.54		

Hu. 1449. C.P.D. —48° 1966

R.A. 8^h 46^m 16^s; Decl. —48° 06′.9
(8.8 . . . 10.0) 80° 0″.8

Hu. 1450. C.P.D. —48° 2072

R.A. 8^h 52^m 04^s; Decl. —48° 40′.6
(9.0 . . . 10.0) 160° 1″

Hu. 1451. C.P.D. —47° 2945

R.A. 8^h 52^m 30^s; Decl. —47° 22′.8
(8.8 . . . 9.2) 320° 0″.8

Hu. 1452. C.P.D. —43° 3186

R.A. 8^h 53^m 13^s; Decl. —43° 03′.8
(8.8 . . . 9.2)

1913.020	144.5	1.28	6.4	300
.036	143.1	1.27	6.8	300
.088	143.9	1.33	6.3	300
1913.05	143.8	1.29		

Hu. 1453. C.P.D. —43° 3257

R.A. 8^h 56^m 59^s; Decl. —43° 45′.6
(8.5 . . . 10.5)

1913.020	174.2	4.06	6.4	300
.036	174.4	4.27	6.9	300
.088	175.3	4.00	6.5	300
1913.05	174.6	4.11		

Hu. 1454. C.P.D. —47° 3073

R.A. 9^h 02^m 05^s; Decl. —47° 40′.8
(8.5 . . . 10.5) 320° 1″.2

Hu. 1455. C.P.D. — 47° 3109

R.A. 9h 05m 02s; Decl. — 47° 13′.5
(8.5 . . . 10.5) 110° 1″

Hu. 1456. C.P.D. — 42° 3467

R.A. 9h 08m 12s; Decl. — 42° 58′.5
(8.5 . . . 12.0)

1912.916	159.8	5.36	6.8	300
1913.020	156.3	5.29	7.2	300
.195	159.8	....	7.4	300
1913.04	158.6	5.33		

Hu. 1457. C.P.D. — 54° 2113

R.A. 9h 10m 38s; Decl. — 54° 28′.4
(8.8 . . . 9.5)

1913.110	265.5	1.12	6.5	300
.151	263.8	1.27	8.0	300
.157	266.1	1.33	6.7	300
1913.14	265.1	1.24		

Hu. 1458. C.P.D. — 51° 2051

R.A. 9h 11m 17s; Decl. — 51° 38′.2
(9.8 . . . 11.0) ... 1″.5

Hu. 1459. C.P.D. — 49° 2412

R.A. 9h 17m 21s; Decl. — 49° 08′.0
(8.5 . . . 12.0) 80° 5″

Hu. 1460. C.P.D. — 49° 2452

R.A. 9h 20m 42s; Decl. — 49° 32′.9
(9.5 . . . 11.0) 130° 1″.5

Hu. 1461. C.P.D. — 54° 2319

R.A. 9h 24m 00s; Decl. — 54° 33′.8
(9.5 . . . 9.5) ... 1″

Hu. 1462. C.P.D. — 48° 2548

R.A. 9h 30m 52s; Decl. — 48° 26′.7
(8.5 . . . 10.0) 320° 2″

Hu. 1463. C.P.D. — 47° 3415

R.A. 9h 31m 00s; Decl. — 47° 26′.1
(10 . . . 11.0) 300° 2″

Hu. 1464. C.P.D. — 47° 3423

R.A. 9h 31m 19s; Decl. — 47° 28′.1
(9.5 . . . 9.5) 250°, 5″

Hu. 1465. C.P.D. — 49° 2622

R.A. 9h 33m 01s; Decl. — 49° 26′.1
(7.5 . . . 13.0) 200° 4″

Hu. 1466. C.P.D. — 54° 2519

R.A. 9h 33m 52s; Decl. — 54° 8′.8
(9.0 . . . 11.5)

1913.122	215.6	3.84	6.9	300
.144	220.7	3.68	7.9	300
.151	216.7	3.56	8.4	300
1913.14	217.7	3.69		

Hu. 1467. C.P.D. — 49° 2640

R.A. 9h 34m 22s; Decl. — 49° 56′.7
(7.8 . . . 12.0) 300° 6″

Hu. 1468. C.P.D. — 57° 2273

R.A. 9h 39m 58s; Decl. — 57° 03′.9
(8.5 . . . 11.5)

1913.297	201.1	4.07	13.3	300

Hu. 1469. C.P.D. — 57° 2277

R.A. 9h 40m 12s; Decl. — 57° 21′.3
(8.5 . . . 11.0)

1913.184	259.1	5.39	7.4	670
.297	257.1	5.59	13.6	300
1913.24	258.1	5.49		

Hu. 1470. C.P.D. — 49° 2840

R.A. 9h 45m 32s; Decl. — 49° 02′.2
(7.8 . . . 11.0) 20° 6″

Hu. 1471. C.P.D. — 57° 2379

R.A. 9h 47m 00s; Decl. — 57° 32′.1
(9.0 . . . 10.8)

1913.184	165.9	2.15	7.5	670
.297	169.6	2.37	13.8	300
1913.24	167.8	2.26		

Hu. 1472. C.P.D. — 49° 2958

R.A. 9h 52m 30s; Decl. — 49° 16′.5
(7.7 . . . 12.5) 360° 1″.5

Hu. 1473. C.P.D. — 45° 4343

R.A. 9h 58m 41s; Decl. — 45° 39′.3
(8.8 . . . 10.0)

1913.036	328.2	1.03	7.4	300

Hu. 1474. C.P.D. — 54° 3101

R.A. 10h 00m 59s; Decl. — 54° 04′.8
(9.2 . . . 9.8)

1913.110	179.5	0.86	7.4	300
.151	176.6	0.91	8.6	300
.297	178.5	0.73	14.1	300
1913.19	178.2	0.83		

Hu. 1475. C.P.D. — 44° 4788

R.A. 10^h 19^m 42^s; Decl. — 44° 26'.1

(8.8 . . . 9.2)

1913.020	261.1	2.49	8.1	300
.034	260.5	2.28	7.8	300
.036	260.7	2.42	8.3	300
.195	260.8	2.16	8.5	300
1913.07	260.8	2.34		

Hu. 1476. C.P.D. — 57° 3793

R.A. 10^h 42^m 03^s; Decl. — 57° 17'.9

(8.8 . . . 11.0)

1913.157	109.0	4.68	8.5	300
.184	111.9	4.49	8.2	670
.187	110.3	4.61	7.9	270
1913.17	110.7	4.59		

Hu. 1477. C.P.D. — 55° 3928

R.A. 10^h 46^m 58^s; Decl. — 55° 29'.7

(9.2 . . . 9.5)

1913.184	237.1	6.02	8.4	300
.187	236.6	5.83	8.2	300
.297	236.8	6.15	14.5	300
1913.22	236.8	6.00		

Hu. 1478. C.P.D. — 57° 9643

R.A. 10^h 49^m 10^s; Decl. — 57° 46'.5

(9.2 . . . 10.0)

1913.187	330.6	6.08	8.8	240

Hu. 1479. C.P.D. — 56° 3987

R.A. 10^h 49^m 16^s; Decl. — 56° 26'.9

(9.5 . . . 9.5)

1913.107	109.5	1.12	8.0	300
.110	105.3	1.30	8.3	300
.187	105.9	1.20	8.6	300
.297	106.0	1.03	14.8	300
1913.18	106.7	1.17		

Hu. 1480. C.P.D. — 49° 3921

R.A. 10^h 57^m 10^s; Decl. — 49° 45'.4

(8.8 . . . 11.5) 290° 4"

Hu. 1481. C.P.D. — 55° 4171

R.A. 11^h 4^m 03^s; Decl. — 55° 28'.8

(9.0 . . . 9.5) 300° 0".8

Hu. 1482. C.P.D. — 55° 4293

R.A. 11^h 14^m 34^s; Decl. — 55° 44'.2

(9.0 . . . 9.2)

1913.107	354.7	3.53	9.3	300
.113	354.0	3.70	8.5	300
1913.11	354.4	3.62		

Hu. 1483. C.P.D. — 56° 4430

R.A. 11^h 16^m 02^s; Decl. — 56° 42'.9

(9.0 . . . 12.0)

1913.113	51.9	1.74	8.7	300

Hu. 1484. C.P.D. — 22° 5036

R.A. 11^h 30^m 00^s; Decl. — 22° 9'.5

(9.0 . . . 11.0)

1913.277	330.2	1.84	9.7	300

Hu. 1485. C.P.D. — 57° 4979

R.A. 11^h 40^m 22^s; Decl. — 57° 20'.2

(8.0 . . . 11.8 . . . 11.5)

		AB		
1913.157	317.1	2.91	9.7	300
.187	317.8	2.96	10.0	300
1913.17	317.4	2.94		
		AC		
1913.157	276.0	7.84	9.8	240
.184	275.8	8.06	9.9	240
.187	275.9	7.94	9.9	240
1913.18	275.9	7.95		

Hu. 1486. C.P.D. — 54° 4788

R.A. 11^h 43^m 18^s; Decl. — 54° 48'.8

(8.5 . . . 9.2)

1913.157	76.9	2.52	10.0	240
.184	79.5	2.40	9.2	300
.187	76.2	2.64	9.5	670
1913.18	77.5	2.52		

Hu. 1487. C.P.D. — 55° 4673

R.A. 11^h 44^m 41^s; Decl. — 55° 11'.6

(8.8 . . . 10.0)

1913.157	238.4	1.32	10.1	300
.184	240.3	1.23	9.4	240
.187	237.9	1.32	9.7	670
1913.18	238.9	1.29		

Hu. 1488. C.P.D. — 57° 5105

R.A. 11h 49m 29s; Decl. — 57° 17′.4
(8.8 . . . 10.5)

1913.107	17.8	3.46	9.9	300
.144	16.4	3.20	9.5	300
.151	16.2	3.23	9.3	300
1913.14	16.8	3.30		

Hu. 1489. C.P.D. — 21° 5116

R.A. 11h 49m 32s; Decl. — 21° 20′.2
(8.0 . . . 12.0) pr. 1″.5

Hu. 1490. C.P.D. — 24° 4754

R.A. 11h 50m 41s; Decl. — 24° 47′.1
(8.5 . . . 8.5)

1913.277	82.9	0.68	10.0	670

Hu. 1491. C.P.D. — 56° 4994

R.A. 11h 58m 18s; Decl. — 56° 30′.1
(8.5 . . . 9.2)

1913.144	320.7	0.91	9.8	300
.151	318.0	0.88	9.8	300
1913.15	319.4	0.89		

Hu. 1492. C.P.D. — 25° 4872

R.A. 11h 59m 36s; Decl. — 25° 5′.7
(9.0 . . . 9.5) 100° 0″.5

Hu. 1493. C.P.D. — 44° 5873

R.A. 12h 5m 17s; Decl. — 44° 22′.5
(9.5 . . . 9.5)

1913.238	142.6	0.65	9.7	300
.241	146.3	0.88	9.7	300
1913.24	144.5	0.77		

Hu. 1494. C.P.D. — 42° 5907

R.A. 12h 32m 44s; Decl. — 42° 17′.8
(9.2 . . . 9.2)

1913.261	145.7	1.18	10.0	670

Hu. 1495. C.P.D. — 55° 5184

R.A. 12h 34m 33s; Decl. — 55° 12′.1
(9.5 . . . 9.5)

1913.151	274.9	0.95	10.3	300

Hu. 1496. C.P.D. — 44° 6046

R.A. 12h 37m 08s; Decl. — 44° 18′.0
(8.8 . . . 13.0)

1913.261	314.9	2.72	10.2	300

Hu. 1497. C.P.D. — 25° 4995

R.A. 12h 37m 43s; Decl. — 25° 23′.1
(9.0 . . . 10.0)

1913.258	341.5	1.61	10.1	300
.277	342.2	1.89	10.7	300
1913.27	341.9	1.75		

Hu. 1498. C.P.D. — 43° 5902

R.A. 12h 41m 50s; Decl. — 43° 24′.2
(8.5 . . . 12.0)

1913.261	262.4	5.10	10.5	300

Hu. 1499. C.P.D. — 44° 6107

R.A. 12h 45m 20s; Decl. — 44° 48′.7
(9.2 . . . 9.2)

1913.261	293.9	1.42	10.7	670

Hu. 1500. C.P.D. — 23° 5703

R.A. 13h 04m 04s; Decl. — 23° 30′.7
(7.5 . . . 11.8)

1913.258	31.1	3.55	10.5	300
.277	30.0	3.68	11.2	300
1913.27	30.6	3.62		

Hu. 1501. C.P.D. — 24° 5022

R.A. 13h 08m 13s; Decl. — 24° 13′.6
(9.0 . . . 9.0) 30° 0″.3

Hu. 1502. C.P.D. — 25° 5153

R.A. 13h 12m 51s; Decl. — 25° 13′.2
(9.0 . . . 10.0) 70° 1″

Hu. 1503. C.P.D. — 22° 5590

R.A. 13h 58m 36s; Decl. — 22° 08′.4
(7.2 . . . 10.5)

1913.258	196.7	0.90	11.0	670

Hu. 1504. C.P.D. — 45° 6669

R.A. 13h 55m 51s; Decl. — 45° 42′.0
(9.0 . . . 10.0)

1913.261	143.4	3.08	11.4	300
.294	144.2	2.82	10.9	300
1913.28	143.8	2.95		

Hu. 1505. C.P.D. — 42° 6519

R.A. 13h 56m 23s; Decl. — 42° 48′.1
(9.0 . . . 9.4)

1913.261	126.7	2.43	11.1	300
.294	125.9	2.45	10.8	300
1913.28	126.3	2.44		

Hu. 1506. C.P.D. —44° 6659

R.A. 14^h 01^m 10^s; Decl. —44° 58′.9
(8.7 . . . 10.0 . . . 11.0)

		AB		
1913.261	258.4	37.45	11.5	300
		BC		
1913.261	32.7	4.39	11.5	300
.294	32.3	4.11	11.0	300
1913.28	32.5	4.25		

Hu. 1507. C.P.D. —43° 6503

R.A. 14^h 12^m 50^s; Decl. —43° 48′.8
(8.5 . . . 9.5)

1913.261	83.2	2.87	11.8	300
.294	83.3	2.87	11.4	300
.624	85.7	2.50	18.3	300
1913.39	84.1	2.75		

Hu. 1508. C.P.D. —45° 6879

R.A. 14^h 23^m 57^s; Decl. —45° 32′.5
(8.7 . . . 12.0)

1913.261	314.1	5.96	12.0	300
.294	312.8	5.98	11.9	300
1913.28	313.5	5.97		

Hu. 1509. C.P.D. —45° 6910

R.A. 14^h 27^m 19^s; Decl. —45° 26′.3
(8.1 . . . 11.3)

1913.261	233.8	2.01	12.2	300
.294	236.7	1.60	12.0	670
1913.28	235.2	1.80		

Hu. 1510. C.P.D. —43° 6650

R.A. 14^h 33^m 36^s; Decl. —43° 42′.2
(9.0 . . . 9.5)

1913.261	139.4	0.76	12.3	670

Hu. 1511. C.P.D. —24° 5376

R.A. 14^h 41^m 01^s; Decl. —24° 05′.3
(9.0 . . . 9.5)

1913.258	312.1	1.06	12.5	670
.277	309.2	0.90	12.5	670
1913.27	310.7	0.98		

Hu. 1512. C.P.D. —23° 5987

R.A. 14^h 42^m 04^s; Decl. —23° 10′.0
(9.0 . . . 9.0)

1913.258	51.0	1.06	12.7	670
.277	48.6	1.00	12.6	670
1913.27	49.8	1.03		

Hu. 1513. C.P.D. —42° 6913

R.A. 14^h 59^m 17^s; Decl. —42° 37′.3
(8.8 . . . 9.3)

1913.294	180.9	2.31	12.7	670
.624	181.7	1.93	18.6	300
1913.46	181.3	2.12		

Hu. 1514. C.P.D. —41° 7146

R.A. 15^h 12^m 10^s; Decl. —41° 58′.9
(8.8 . . . 9.5)

1913.294	252.2	2.74	12.8	670

Hu. 1515. C.P.D. —24° 5501

R.A. 15^h 12^m 52^s; Decl. —24° 31′.3
(8.5 . . . 12.0)

1913.258	153.9	1.94	13.1	300
.277	158.1	1.98	13.5	300
1913.27	156.0	1.96		

Hu. 1516. C.P.D. —22° 6064

R.A. 15^h 37^m 01^s; Decl. —22° 56′.4
(9.0 . . . 10.0)

1913.258	248.4	1.48	13.3	300
.277	248.2	1.61	13.7	300
1913.27	248.3	1.54		

Hu. 1517. C.P.D. —45° 8030

R.A. 16^h 26^m 58^s; Decl. —45° 22′.0
(10.0 . . . 11.0) 90° 0″.5

Hu. 1518. C.P.D. —44° 7988

R.A. 16^h 30^m 19^s; Decl. —44° 38′.0
(8.6 . . . 10.0) 250° 1″

Hu. 1519. C.P.D. —42° 7476

R.A. 16^h 33^m 52^s; Decl. —42° 38′.5
(9.0 . . . 10.0)

1913.294	73.0	1.06	13.0	670
.441	75.5	1.17	13.8	300
1913.37	74.3	1.12		

Hu. 1520. C.P.D. —45° 8134

R.A. 16^h 38^m 27^s; Decl. —45° 13′.9
(8.5 . . . 8.5)

1913.258	175.0	0.44	13.7	670

Hu. 1521. C.P.D. —44° 8253

R.A. 16^h 59^m 20^s; Decl. —44° 33′.0
(9.0 . . . 12.0) 190° 3″

Hu. 1522. C.P.D. —25° 5949

R.A. 17ʰ 03ᵐ 54ˢ; Decl. —25° 08′.6
(9.0 . . . 10.0) 270° 1″

Hu. 1523. C.P.D. —43° 8026

R.A. 17ʰ 15ᵐ 10ˢ; Decl. —43° 40′.9
(8.0 . . . 11.0)

1913.441	267.0	7.26	14.5	300
.709	266.7	7.43	21.1	300
1913.57	266.8	7.35		

Hu. 1524. C.P.D. —22° 6446

R.A. 17ʰ 40ᵐ 27ˢ; Decl. —22° 36′.7
(9.5 . . . 9.5) 330° 1″

Hu. 1525. C.P.D. —46° 9068

R.A. 17ʰ 55ᵐ 10ˢ; Decl. —46° 26′.9
(8.0 . . . 9.5) 270° 0″.8

Hu. 1526. C.P.D. —46° 9332

R.A. 18ʰ 20ᵐ 08ˢ; Decl. —46° 23′.1
(9.0 . . . 9.0) 30° 1″.5

Hu. 1527. C.P.D. —45° 9398

R.A. 18ʰ 30ᵐ 14ˢ; Decl. —45° 51′.3
(8.0 . . . 11.0)

1913.439	310.7	4.70	16.3	300
.710	311.2	4.58	23.1	300
1913.67	311.0	4.64		

Hu. 1528. C.P.D. —47° 9026

R.A. 18ʰ 35ᵐ 02ˢ; Decl. —47° 04′.8
(8.7 . . . 11.0) 220° 1″.5

Hu. 1529. C.P.D. —41° 9137

R.A. 19ʰ 26ᵐ 30ˢ; Decl. —41° 41′.5
(9.0 . . . 10.0)

1913.439	305.5	1.99	16.0	300
.710	304.6	2.32	0.2	300
.792	303.9	2.08	23.9	300
1913.65	304.7	2.13		

Hu. 1530. C.P.D. —46° 9768

R.A. 19ʰ 31ᵐ 23ˢ; Decl. —46° 58′.3
(9.0 . . . 9.5) 200° 0″.8

Hu. 1531. C.P.D. —54° 9663

R.A. 20ʰ 09ᵐ 31ˢ; Decl. —54° 55′.7
(9.5 . . . 9.5) 180° 2″

Hu. 1532. C.P.D. —54° 9711

R.A. 20ʰ 23ᵐ 52ˢ; Decl. —54° 17′.3
(9.0 . . . 10.5)

1913.814	279.5	0.86	24.0	400
.836	280.7	0.69	0.7	400
1913.82	280.1	0.77		

Hu. 1533. C.P.D. —45° 10067

R.A. 20ʰ 51ᵐ 59ˢ; Decl. —45° 48′.1
(8.8 . . . 11.0)

1913.792	52.6	4.77	0.9	300
.819	53.4	4.51	0.7	400
1913.81	53.0	4.64		

Hu. 1534. C.P.D. —56° 9604

R.A. 21ʰ 05ᵐ 01ˢ; Decl. —56° 45′.9
(7.8 . . . 12.2)

1913.814	345.4	5.17	1.5	300
.828	342.1	5.24	1.3	400
.831	344.0	5.49	1.7	300
1913.82	343.8	5.30		

Hu. 1535. C.P.D. —56° 9606

R.A. 21ʰ 05ᵐ 21ˢ; Decl. —56° 22′.3
(8.5 . . . 12.0) 225° 8″

Hu. 1536. C.P.D. —56° 9630

R.A. 21ʰ 13ᵐ 30ˢ; Decl. —56° 18′.7
(7.5 . . . 12.0)

1913.803	171.3	6.03	1.5	400
.831	172.2	5.64	1.8	300
.836	172.3	5.81	1.3	300
1913.82	171.9	5.83		

Hu. 1537. C.P.D. —55° 9581

R.A. 21ʰ 15ᵐ 27ˢ; Decl. —55° 06′.4
(8.5 . . . 12.0)

1913.836	351.7	3.63	1.6	300

Hu. 1538. C.P.D. —48° 10598

R.A. 21ʰ 24ᵐ 42ˢ; Decl. —48° 10′.6
(8.8 . . . 12.0)

1913.819	303.5	1.33	2.4	400

Hu. 1539. C.P.D. —45° 10160

R.A. 21ʰ 46ᵐ 23ˢ; Decl. —45° 12′.2
(9.0 . . . 9.5)

1913.690	84.1	1.33	19.3	300
.710	84.0	1.57	1.5	300
.792	85.5	1.23	1.0	300
.819	82.9	1.61	0.9	400
1913.75	84.1	1.44		

Hu. 1540. C.P.D. —46° 10270

R.A. 21h 32m 39s; Decl. —46° 44'.9
(8.5 . . . 11.5)

1913.690	309.9	3.02	19.5	300
.819	309.7	3.24	2.6	400
.833	307.7	3.18	1.0	300
1913.78	309.1	3.15		

Hu. 1541. C.P.D. —49° 11495

R.A. 21h 40m 14s; Decl. —49° 25'.5
(8.5 . . . 11.0)

1913.792	100.0	5.88	2.5	300
.819	100.1	5.63	...	400
.833	100.6	5.66	...	300
1913.81	100.2	5.72		

Hu. 1542. C.P.D. —54° 9951

R.A. 21h 57m 44s; Decl. —54° 29'.2
(9.0 . . . 12.0) 120° 6"

Hu. 1543. C.P.D. —57° 10042

R.A. 22h 00m 14s; Decl. —57° 02'.7
(8.2 . . . 8.2) ... 0".8

Hu. 1544. C.P.D. —54° 10202

R.A. 22h 27m 20s; Decl. —54° 15'.2
(9.2 . . . 10.0)

1913.803	149.2	0.79	2.2	400

Hu. 1545. C.P.D. —45° 10338

R.A. 22h 41m 02s; Decl. —45° 54'.5
(8.0 . . . 9.0)

1913.690	40.3	1.33	20.1	300
.710	45.1	1.27	2.0	300
.792	41.9	1.35	1.7	670
1913.73	42.4	1.32		

Hu. 1546. C.P.D. —55° 9937

R.A. 22h 54m 31s; Decl. —55° 56'.2
(8.5 . . . 10.0) 100° 1"

Hu. 1547. C.P.D. —48° 10854

R.A. 22h 59m 12s; Decl. —48° 27'.5
(7.8 . . . 10.5)

1913.690	155.8	3.11	20.9	300
.819	154.3	2.94	3.9	400
.833	156.1	2.89	1.7	400
1913.78	155.4	2.98		

Hu. 1548. C.P.D. —55° 9961

R.A. 23h 02m 37s; Decl. —55° 18'.0
(8.6 . . . 11.0) 270° 2"

Hu. 1549. C.P.D. —54° 10225

R.A. 23h 05m 40s; Decl. —54° 52'.0
(7.0 . . . 9.0) ... 1"

Hu. 1550. C.P.D. —42° 9601

R.A. 23h 34m 28s; Decl. —42° 16'.9

1913.792	181.5	0.63	1.9	670

Ann Arbor, Michigan,
May 4, 1914.

DOUBLE STARS DISCOVERED AT LA PLATA.

BY W. J. HUSSEY.

Fourteenth Catalogue

The double stars of this catalogue were discovered and measured with the 17-inch Gautier refractor of the La Plata Observatory. Prior to February 11, 1914, the measures were made with the micrometer belonging to the small equatorial and those subsequent to that date with the new filar micrometer, furnished by The Warner & Swasey Company. In nearly all cases each position angle given is derived from the mean of four settings of the circle and each recorded distance from the mean of three measures of the double distance. The right ascensions and declinations are for the epoch 1875.0. In the measures, the last two columns contain the sidereal times of observation and the powers used.

Ann Arbor, Michigan.
February, 27, 1915.

Hu. 1551. C.P.D. —53° 9

R.A. 0h 2m 26s; Decl. —53° 1'.4
(8.0 . . . 11.5)

1914.687	126°.8	8".27	21h.3	360

Hu. 1552. C.P.D. —51° 28

R.A. 0h 9m 17s; Decl. —51° 0'.1
(9.5 . . . 9.8)

1914.687	66.6	2.04	22.0	360

Hu. 1553. C.P.D. —59° 114

R.A. 1h 34m 25s; Decl. —59° 12'.9
(8.8 . . . 9.0)

1914.882	370.0	1.81	5.5	360

Hu. 1554. C.P.D. — 54° 369

R.A. $1^h\ 38^m\ 16^s$; Decl. — 54° 51′.9
(9.0 . . . 9.2)

1914.764	281.8	5.71	23.3	360
.775	281.6	5.62	22.9	360
1914.77	281.7	5.67		

Hu. 1555. C.P.D. — 57° 355

R.A. $1^h\ 42^m\ 40^s$; Decl. — 57° 4′.4
(9.1 . . . 9.8)

1914.764	91.6	8.74	23.5	360
.775	90.4	8.73	23.2	360
1914.77	91.0	8.74		

Hu. 1556. C.P.D. — 56° 257

R.A. $1^h\ 51^m\ 57^s$; Decl. — 51° 5′0
(9.5 . . . 10.5)

1914.756	329.7	0.68	22.8	450

Hu. 1557. C.P.D. — 54° 401

R.A. $1^h\ 54^m\ 5^s$; Decl. — 54° 8′.1
(9.2 . . . 10.5)

1914.764	105.6	2.33	23.0	360
.774	110.4	2.22	23.4	360
1914.77	108.0	2.27		

Hu. 1558. C.P.D. — 54° 409

R.A. $1^h\ 56^m\ 40^s$; Decl. — 54° 36′.9
(8.3 . . . 11.5)

1914.764	51.6	3.95	22.8	360

Hu. 1559. C.P.D. — 51° 267

R.A. $1^h\ 57^m\ 41^s$; Decl. — 51 ° 20′.6
(9.2 . . . 9.5)

1914.756	313.0	1.00	23.7	360

Hu. 1560. C.P.D. — 55° 393

R.A. $2^h\ 4^m\ 4^s$; Decl. — 55° 26′.6
(8.8 . . . 9.2)

1914.775	94.6	0.58	23.7	360

Hu. 1561. C.P.D. — 24° 321

R.A. $2^h\ 41^m\ 47^s$; Decl. — 24° 12′.2
(9.0 . . . 9.5)

1914.750	312.7	0.91	0.0	360

Hu. 1562. C.P.D. — 53° 489

R.A. $2^h\ 47^m\ 49^s$; Decl. — 53° 4′.4
(8.8 . . . 8.8)

1914.761	59.0	0.52	0.1	450

Hu. 1563. C.P.D. — 50° 408

R.A. $2^h\ 48^m\ 46^s$; Decl. — 50° 10′.9
(9.0 . . . 11.0)

1914.756	8.0	2.66	0.3	360

Hu. 1564. C.P.D. — 51° 393

R.A. $3^h\ 15^m\ 41^s$; Decl. — 51° 0′.1
(9.0 . . . 9.5)

1914.775	244.6	1.62	1.0	360

Hu. 1565. C.P.D. — 53° 554

R.A. $3^h\ 17^m\ 40^s$; Decl. — 53° 52′.8
(9.2 . . . 9.2)

1914.775	103.7	1.76	0.6	360

Hu. 1566. C.P.D. — 51° 730

R.A. $5^h\ 30^m\ 38^s$; Decl. — 51° 9′.1
(9.5 . . . 9.5)

1914.978	175.2	0.76	2.8	360

Hu. 1567. C.P.D. — 61° 491

R.A. $5^h\ 36^m\ 40^s$; Decl. — 61° 33′.8
(8.6 . . . 9.2)

1914.948	58.3	0.98	2.1	450
.956	58.4	0.87	2.3	360
1914.95	58.4	0.93		

Hu. 1568. C.P.D. — 50° 826

R.A. $5^h\ 38^m\ 43^s$; Decl. — 50° 4′.1
(8.8 . . . 9.0)

1914.975	48.4	0.58	2.8	450
.978	46.6	0.57	3.3	450
1914.98	47.5	0.58		

Hu. 1569. C.P.D. — 50° 829

R.A. $5^h\ 40^m\ 29^s$; Decl. — 50° 31′.1
(9.0 . . . 10.2)

1914.975	71.2	1.13	2.6	360
978	71.4	1.07	3.0	450
1914.98	71.3	1.10		

Hu. 1570. C.P.D. — 52° 814

R.A. $5^h\ 55^m\ 13^s$; Decl. — 52° 12′.9
(9.0 . . . 9.2)

1914.975	36.2	0.82	3.6	360
.978	37.1	0.82	3.6	360
1914.98	36.7	0.82		

Hu. 1571. C.P.D. — 50° 878

R.A. 5^h 55^m 58^s; Decl. — 50° 41′.3
(9.0 . . . 11.0)

1914.975	157.5	0.73	3.4	360

Hu. 1572. C.P.D. — 52° 852

R.A. 6^h 3^m 31^s; Decl. — 52° 18′.3
(8.6 . . . 8.6)

1914.972	49.0	0.43	3.2	450
.975	46.9	0.57	4.0	450
1914.97	48.0	0.50		

Hu. 1573. C.P.D. — 52° 867

R.A. 6^h 6^m 0^s; Decl. — 52° 6′.9
(8.2 . . . 8.8)

1914.972	182.6	0.22	3.3	450

Hu. 1574. C.P.D. — 51° 871

R.A. 6^h 11^m 19^s; Decl. — 51° 32′.8
(9.2 . . . 12.0)

1914.972	234.1	1.07	3.5	360

Hu. 1575. C.P.D. — 61° 630

R.A. 6^h 18^m 39^s; Decl. — 61° 28′.6
(8.3 . . . 10.5)

1914.956	248.0	1.12	2.8	360
.961	242.9	1.31	2.7	450
.964	245.9	0.96	3.9	450
1914.96	245.6	1.13		

Hu. 1576. C.P.D. — 58° 712

R.A. 6^h 26^m 29^s; Decl. — 58° 16′.2
(9.1 . . . 9.1)

1914.956	48.6	0.49	3.7	360
.963	52.6	0.44	2.9	450
1914.96	50.6	0.47		

Hu. 1577. C.P.D. — 61° 684

R.A. 6^h 35^m 0^s; Decl. — 61° 29′.2
(8.8 . . . 12.5)

1914.956	141.4	2.58	3.3	360
.963	142.7	2.78	3.0	360
1914.96	142.0	2.68		

Hu. 1578. C.P.D. — 53° 1159

R.A. 6^h 44^m 39^s; Decl. — 53° 25′.0
(9.5 . . . 9.5)

1914.972	138.3	1.05	4.4	360

Hu. 1579. C.P.D. — 59° 725

R.A. 6^h 53^m 44^s; Decl. — 59° 22′.1
(9.0 . . . 9.2)

1914.961	33.4	1.10	4.3	360
.964	31.4	1.08	4.6	450
1914.96	32.4	1.09		

Hu. 1580. C.P.D. — 61° 749

R.A. 6^h 56^m 29^s; Decl. — 61° 21′.0
(8.8 . . . 9.0)

1914.961	12.2	0.54	3.9	360
.964	7.7	0.64	4.5	450
1914.96	10.0	0.59		

Hu. 1581. C.P.D. — 52° 1081

R.A. 7^h 4^m 0^s; Decl. — 52° 16′.9
(8.4 . . . 10.5)

1914.972	54.4	1.30	4.7	360
1915.027	58.5	1.00	4.8	360
1915.00	56.5	1.15		

Hu. 1582. C.P.D. — 59° 776

R.A. 7^h 6^m 8^s; Decl. — 59° 26′.7
(9.0 . . . 11.8)

1914.961	215.5	6.62	4.7	360
.964	214.9	6.54	4.7	450
1914.96	215.2	6.58		

Hu. 1583. C.P.D. — 59° 873

R.A. 7^h 39^m 14^s; Decl. — 59° 42′.4
(8.2 . . . 8.4)

1914.942	243.1	1.06	4.2	360
.956	240.0	0.90	5.1	450
.959	242.9	0.90	4.9	360
1914.95	242.0	0.95		

Hu. 1584. C.P.D. — 59° 881

R.A. 7^h 40^m 19^s; Decl. — 59° 8′.6
(8.5 . . . 11.2)

1914.942	318.0	....	4.4	360
.956	319.0	2.78	4.9	360
.959	320.1	2.85	5.1	360
1914.95	319.0	2.82		

Hu. 1585. C.P.D. — 58° 986

R.A. 7^h 43^m 15^s; Decl. — 58° 38′.9
(8.0 . . . 12.2)

1914.956	71.2	1.62	4.7	450
.959	66.7	1.64	5.2	360
1914.96	69.0	1.63		

Hu. 1586. C.P.D. — 52° 1284

R.A. 7^h 44^m 32^s; Decl. — 52° 51′.9

(9.0 . . . 9.4)

1914.972	266.0	2.33	5.2	360
.975	262.4	2.36	4.4	360
1915.027	265.4	2.17	5.3	360
1914.99	264.6	2.29		

Hu. 1587. C.P.D. — 53° 1473

R.A. 7^h 51^m 12^s; Decl. — 53° 38′.9

(9.2 . . . 9.8)

1914.975	293.7	2.18	4.5	360
1915.027	293.2	1.90	5.3	360
1915.00	293.5	1.99		

Hu. 1588. C.P.D. — 50° 1722

R.A. 8^h 37^m 26^s; Decl. — 50° 11′.6

(9.0 . . . 11.0)

1914.967	66.4	1.18	5.3	360
.972	70.6	1.08	6.1	360
1914.97	68.5	1.13		

Hu. 1589. C.P.D. — 52° 1648

R.A. 8^h 42^m 38^s; Decl. — 52° 40′.3

(8.2 . . . 11.8)

1914.967	93.1	3.34	6.0	360
.972	91.8	3.34	6.5	450
1914.97	92.5	3.34		

Hu. 1590. C.P.D. — 52° 1652

R.A. 8^h 42^m 44^s; Decl. — 52° 23′.1

(7.8 . . . 8.3)

1914.967	333.9	0.36	5.7	450
.972	336.8	0.33	6.3	450
1914.97	335.4	0.35		

Hu. 1591. C.P.D. — 59° 1121

R.A. 8^h 44^m 46^s; Decl. — 59° 9′.5

(8.0 . . . 12.5)

1914.959	222.4	5.52	6.1	360
.964	222.1	5.46	6.2	360
1914.96	222.3	5.49		

Hu. 1592 C.P.D. — 58° 1625

R.A. 9^h 41^m 26^s; Decl. — 58° 53′.9

(8.0 . . . 11.2)

1914.956	285.1	2.57	6.3	360
.959	288.5	2.47	6.6	360
1914.96	286.8	2.52		

Hu. 1593. C.P.D. — 61° 1441

R.A. 9^h 59^m 43^s; Decl. — 61° 16′.6

(7.5 . . . 7.8)

1914.956	349.0	1.23	7.5	450
.959	349.7	1.30	6.8	360
1914.96	349.4	1.27		

Hu. 1594. C.P.D. — 50° 3018

R.A. 10^h 0^m 20^s; Decl. — 50° 42′.5

(7.0 . . . 7.0)

1914.967	82.9	0.23	6.9	450
1915.027	76.7	0.23	7.3	450
1915.00	79.8	0.23		

Hu. 1595. C.P.D. — 61° 1477

R.A. 10^h 3^m 35^s; Decl. — 61° 37′.7

(7.8 . . . 11.8)

1914.959	136.7	2.91	6.9	360
.964	140.4	3.01	7.2	360
1914.96	138.6	2.96		

Hu. 1596. C.P.D. — 58° 2031

R.A. 10^h 10^m 53^s; Decl. — 58° 8′.8

(9.0 . . . 9.5)

1914.964	338.1	1.17	7.7	360

Hu. 1597. C.P.D. — 59° 2008

R.A. 10^h 11^m 47^s; Decl. — 59° 16′.8

(7.5 . . . 7.5)

1914.956	114.2	0.26	7.5	450
.959	117.2	0.27	7.2	670
1914.96	115.7	0.26		

Hu. 1598. C.P.D. — 50° 3316

R.A. 10^h 13^m 18^s; Decl. — 50° 11′.8

(8.2 . . . 8.5)

1914.967	245.5	0.42	7.2	450
1915.027	242.7	0.41	7.5	450
1915.00	244.1	0.42		

Hu. 1599. C.P.D. — 60° 1881

R.A. 10^h 19^m 24^s; Decl. — 60° 56′.1

(8.6 . . . 9.5)

1914.959	359.8	1.24	7.5	360

Hu. 1600. C.P.D. — 51° 3645

R.A. 10^h 46^m 59^s; Decl. — 51° 31′4

(8.0 . . . 11.0)

1914.967	334.6	1.75	7.8	360
.972	331.7	1.95	7.4	360
1914.97	343.2	1.85		

Hu. 1601. C.P.D. — 53° 4262

R.A. $10^h\ 52^m\ 47^s$; Decl. — 53° 39′.8
(9.5 . . . 9.5)

1914.972	165.4	0.21	8.1	450

Hu. 1602. C.P.D. — 57° 4384

R.A. $11^h\ 5^m\ 28^s$; Decl. — 57° 32′.2
(9.2 . . . 9.8)

1913.107	95.6	3.94	8.8	300
.122	94.8	3.84	9.2	300
.151	95.0	3.97	9.6	300
1913.13	95.1	3.92		

Hu. 1603. C.P.D. — 60° 3300

R.A. $11^h\ 39^m\ 47^s$; Decl. — 60° 13′.5
(9.5 . . . 10.5)

1914.964	42.4	1.70	8.7	360

Hu. 1604. C.P.D. — 52° 5302

R.A. $12^h\ 4^m\ 34^s$; Decl. — 52° 20′.5
(9.2 . . . 9.2)

1914.972	101.2	0.40	9.4	450

Hu. 1605. C.P.D. — 57° 8070

R.A. $16^h\ 24^m\ 55^s$; Decl. — 57° 48′.9
(8.8 . . . 9.5)

1914.695	73.2	4.25	20.0	360
.706	72.8	4.35	20.0	360
1914.70	73.0	4.30		

Hu. 1606. C.P.D. — 54° 7853

R.A. $16^h\ 39^m\ 4^s$; Decl. — 54° 26′.8
(8.8 . . . 9.5)

1914.720	171.9	1.86	20.7	360

Hu. 1607. C.P.D. — 51° 10928

R.A. $18^h\ 25^m\ 23^s$; Decl. — 51° 25′.3
(9.0 . . . 11.5)

1914.819	266.9	2.34	22.6	360

Hu. 1608. C.P.D. — 52° 11520

R.A. $19^h\ 35^m\ 7^s$; Decl. — 52° 27′.6
(8.4 . . . 8.8)

1914.817	251.1	0.38	23.7	450
.858	253.8	0.35	23.8	450
1914.87	252.5	0.37		

Hu. 1609. C.P.D. — 63° 4554

R.A. $19^h\ 46^m\ 39^s$; Decl. — 63° 0′.2
(9.0 . . . 12.0)

1914.849	250.4	2.30	0.2	360
.852	251.3	2.05	0.2	360
1914.85	250.8	2.18		

Hu. 1610. C.P.D. — 52° 11593

R.A. $19^h\ 49^m\ 22^s$; Decl. — 52° 27′.7
(8.8 . . . 11.0)

1914.583	155.8	1.74	17.2	360
.817	154.3	2.08	0.4	450
.858	155.6	2.04	23.9	450
1914.75	155.2	1.95		

Hu. 1611. C.P.D. — 62° 6142

R.A. $19^h\ 58^m\ 15^s$; Decl. — 62° 31′.5
(9.0 . . . 11.5)

1914.849	299.8	1.60	0.9	360
.852	300.8	1.61	0.6	360
1914.85	300.3	1.60		

Hu. 1612. C.P.D. — 50° 11284

R.A. $20^h\ 0^m\ 14^s$; Decl. — 50° 48′.0
(8.8 . . . 9.5)

1914.585	57.9	0.87	18.0	360
.858	58.6	0.96	0.1	450
1914.72	58.3	0.92		

Hu. 1613. C.P.D. — 50° 11306

R.A. $20^h\ 4^m\ 40^s$; Decl. — 50° 41′.5
(8.5 . . . 8.5)

1914.585	310.8	0.56	17.5	670
.858	309.7	0.79	0.2	450
1914.72	310.3	0.67		

Hu. 1614. C.P.D. — 52° 11649

R.A. $20^h\ 7^m\ 3^s$; Decl. — 52° 55′.9
(8.5 . . . 12.5)

1914.858	78.0	1.26	1.6	360

Hu. 1615. C.P.D. — 63° 4590

R.A. $20^h\ 23^m\ 53^s$; Decl. — 63° 44′.1
(7.5 . . . 8.0)

1914.852	359.4	0.39	1.3	450
.873	358.2	0.46	0.7	450
1914.86	358.8	0.43		

Hu. 1616. C.P.D. —64° 4063

R.A. $20^h\ 29^m\ 48^s$; Decl. —64° 37′.1

(8.4 . . . 9.0)

1914.873	83.3	0.77	1.0	450

Hu. 1617. C.P.D. —51° 11541

R.A. $20^h\ 31^m\ 8^s$; Decl. —51° 39′.8

(8.0 . . . 8.8)

1914.585	124.1	0.53	18.5	360
.858	124.2	0.43	1.3	450
1914.72	124.2	0.48		

Hu. 1618. C.P.D. —51° 11553

R.A. $20^h\ 36^m\ 28^s$; Decl. —51° 32′.2

(8.5 . . . 10.5)

1914.583	229.9	0.92	18.2	360
.646	234.2	0.98	18.0	475
.649	234.8	1.03	18.5	360
1914.63	233.0	0.98		

Hu. 1619. C.P.D. —58° 7776

R.A. $20^h\ 37^m\ 6^s$; Decl. —58° 44′.9

(9.0 . . . 12.5)

1914.835	35.6	1.13	23.8	360
.844	36.6	1.05	23.7	360
1914.84	36.1	1.09		

Hu. 1620. C.P.D. —64° 4074

R.A. $20^h\ 38^m\ 8^s$; Decl. —64° 20′.0

(8.8 . . . 10.0)

1914.873	278.0	1.52	1.4	360

Hu. 1622. C.P.D. —61° 6510

R.A. $20^h\ 41^m\ 25^s$; Decl. —61° 52′.8

(8.4 . . . 11.5)

1914.841	299.3	1.31	1.6	360
.844	298.1	1.57	23.8	360
1914.84	298.7	1.44		

Hu. 1623. C.P.D. —52° 11777

R.A. $20^h\ 41^m\ 29^s$; Decl. —52° 45′.4

(8.2 . . . 12.0)

1914.583	243.7	1.52	17.8	360
.858	247.0	1.57	1.4	360
1914.72	245.4	1.55		

Hu. 1624. C.P.D. —59° 7657

R.A. $20^h\ 47^m\ 32^s$; Decl. —59° 32′.9

(8.5 . . . 8.8)

1914.841	262.8	4.05	1.7	360
.844	262.8	4.03	0.2	450
1914.84	262.8	4.04		

Hu. 1625. C.P.D. —58° 7805

R.A. $20^h\ 56^m\ 16^s$; Decl. —58° 13′.8

(8.5 . . . 9.0)

1914.835	230.7	0.59	0.3	450
.841	228.9	0.60	2.1	450
.844	229.5	0.60	0.4	450
1914.84	229.7	0.60		

Hu. 1626. C.P.D. —52° 10827

R.A. $21^h\ 2^m\ 29^s$; Decl. —52° 50′.8

(7.5 . . . 8.0)

1914.635	205.4	0.72	19.3	670
.858	209.9	0.56	1.9	360
1914.75	207.7	0.64		

Hu. 1627. C.P.D. —58° 7816

R.A. $21^h\ 2^m\ 34^s$; Decl. —58° 8′.0

(8.8 . . . 9.0)

1914.835	198.1	1.43	1.3	450
.841	196.5	....	....	450
.844	198.3	1.50	0.6	
1914.84	197.6	1.47		

Hu. 1628. C.P.D. —59° 7689

R.A. $21^h\ 9^m\ 32^s$; Decl. —59° 19′.9

(8.5 . . . 9.0)

1914.835	271.2	1.05	1.1	450
.844	271.1	0.92	0.7	450
1914.84	271.2	0.98		

Hu. 1629. C.P.D. —52° 11878

R.A. $21^h\ 19^m\ 41^s$; Decl. —52° 24′.4

(8.8 . . . 9.2)

1914.583	258.7	1.29	18.8	360
.618	258.7	1.35	18.6	360
.649	253.9	0.95	18.9	360
1914.62	257.1	1.20		

Hu. 1630. C.P.D. —61° 6559

R.A. $21^h\ 20^m\ 52^s$; Decl. —61° 0′.6

(8.8 . . . 9.5)

1914.835	234.1	2.70	2.0	450
.844	233.3	2.71	1.6	450
.847	236.8	2.83	0.8	450
1914.84	234.7	2.78		

Hu. 1631. C.P.D. —60° 7484

R.A. 21^h 22^m 52^s; Decl. —60° 8′.4

(9.0 . . . 9.4)

1914.835	200.9	1.44	1.8	450
.847	206.6	1.24	0.8	450
1914.84	203.8	1.34		

Hu. 1632. C.P.D. —52° 11908

R.A. 21^h 30^m 8^s; Decl. —52° 1′.3

(8.8 . . . 13.0)

1914.817	181.4	1.31	1.3	450

Hu. 1633. C.P.D. —57° 9965

R.A. 21^h 41^m 51^s; Decl. —57° 21′.8

(9.5 . . . 9.5)

1913.836	137.2	1.52	1.7	300

Hu. 1634. C.P.D. —60° 7512

R.A. 21^h 42^m 33^s; Decl. —60° 0′.3

(8.5 . . . 10.5)

1914.838	249.4	2.40	1.9	360
.847	252.7	2.32	1.5	450
1914.84	251.0	2.36		

Hu. 1635. C.P.D. —50° 11634

R.A. 21^h 51^m 40^s; Decl. —50° 50′.4

(8.7 . . . 12.0)

1914.817	264.6	1.02	2.0	360

Hu. 1636. C.P.D. —62° 6311

R.A. 22^h 4^m 7^s; Decl. —62° 35′.8

(8.8 . . . 11.0)

1914.852	293.4	2.66	2.8	360
.873	292.1	2.72	2.5	360
1914.86	292.7	2.69		

Hu. 1637. C.P.D. —61° 6626

R.A. 22^h 4^m 15^s; Decl. —61° 49′.1

(8.5 . . . 10.0)

1914.847	192.9	5.23	2.3	360

Hu. 1638. C.P.D. —52° 12002

R.A. 22^h 9^m 8^s; Decl. —52° 35′.9

(8.0 . . . 9.5)

1914.585	93.1	2.80	19.3	360
.618	91.1	2.56	19.4	360
.635	95.6	2.54	19.3	360
1914.61	93.3	2.63		

Hu. 1639. C.P.D. —50° 11698

R.A. 22^h 16^m 31^s; Decl. —50° 42′.4

(9.0 . . . 9.5)

1914.585	58.5	0.77	19.8	360
.646	59.5	0.63	19.0	475
1914.62	59.0	0.70		

Hu. 1640. C. P. D. —52° 12031

R.A. 22^h 22^m 38^s; Decl. —52° 11′.5

(8.6 . . . 12.0)

1914.585	257.5	2.63	20.0	360
.618	257.0	2.70	19.9	360
.687	258.5	2.59	19.9	360
1914.63	257.7	2.64		

Hu. 1641. C.P.D. —63° 4819

R.A. 22^h 39^m 29^s; Decl. —63° 1′.1

(9.0 . . . 10.5)

1914.849	75.7	1.41	2.8	360

Hu. 1642. C.P.D. —52° 12079

R.A. 22^h 44^m 25^s; Decl. —52° 32′.9

(8.5 . . . 11.5)

1914.646	161.0	6.73	20.7	360
.649	160.5	7.27	20.3	360
.684	162.7	6.61	20.2	360
1914.66	161.4	6.87		

Hu. 1643. C.P.D. —59° 7847

R.A. 22^h 53^m 21^s; Decl. —59° 6′.5

(7.0 . . . 10.0)

1914.835	3.9	1.75	2.2	450

Hu. 1644. C.P.D. —62° 6406

R.A. 23^h 5^m 11^s; Decl. —62° 29′.1

(8.8 . . . 9.9)

1914.882	341.8	0.54	3.0	360

Hu. 1645. C.P.D. —61° 6731

R.A. 23^h 5^m 46^s; Decl. —61° 15′.7

(7.5 . . . 9.0)

1914.835	78.9	0.97	2.9	360
.841	77.9	0.91	3.7	360
1914.84	78.4	0.94		

Hu. 1646. C.P.D. —65° 4118

R.A. 23^h 8^m 5^s; Decl. —65° 56′.4

(9.0 . . . 9.0)

1914.882	307.5	0.33	3.4	450

Hu. 1647. C.P.D. —64° 4346

R.A. $23^h\ 15^m\ 53^s$; Decl. —64° 32′.9

(8.8 . . . 11.0)

1914.882	50.6	8.53	3.7	360

Hu. 1648. C.P.D. —63° 4888

R.A. $23^h\ 19^m\ 10^s$; Decl. —63° 55′.7

(7.2 . . . 12.5)

1914.882	282.4	1.93	3.7	360

Hu. 1649. C.P.D. —43° 9803

R.A. $23^h\ 50^m\ 1^s$; Decl. —43° 59′.2

(9.0 . . . 9.5)

1914.737	265.6	1.04	2.5	360

Hu. 1650. C.P.D. —45° 10495

R.A. $23^h\ 50^m\ 7^s$; Decl. —45° 24′.8

(9.0 . . . 10.0)

1914.737	319.6	4.18	2.7	360

OBSERVATIONS OF SOUTHERN DOUBLE STARS

By W. J. HUSSEY

The following observations of southern double stars were made with the large refractor of the La Plata Observatory during my last two periods of residence in Argentina. The objective of this telescope was made by Paul and Prosper Henry of the Paris Observatory. It has a clear aperture of 433 mm., or 17 inches, and a focal length of 9.6 m. It gives good images for visual work, which is of fundamental importance in the measurement of close pairs. The mounting was made by P. Gautier, of Paris. It is comparatively simple in design, well constructed, and sufficiently rigid for practical purposes. The driving clock has always performed satisfactorily.

Two micrometers have been used in making the measures: a small one originally constructed by P. Gautier for the 8.4-inch refractor of the La Plata Observatory and afterwards modified in the Observatory Shop for use on the large refractor, and a new filar micrometer constructed by The Warner Swasey Company for the large refractor. The small micrometer was used until the new one was received and installed. All the measures since February 11, 1914, have been made with the new micrometer. The telescope and micrometers are briefly described in the first volume of the *Publications* of the La Plata Observatory, to which the reader is referred for further particulars.

In general, each position angle given is derived from the mean of four settings of the circle and each distance is the mean of three measures of the double distance. The numbers in the last two columns are the sidereal times of observation and the powers used. The right ascensions and declinations are for the epoch 1875.0.

ANN ARBOR, MICHIGAN,
MARCH 2, 1915.

h 3391. C.P.D. —58° 42

R.A. $0^h\ 37^m\ 42^s$; Decl. —58° 8′.9

(4.0 . . . 11.0)

1914.852	218°.9	20″.44	2^h.0	370

Innes 707. C.P.D. —47° 90

R.A. $0^h\ 44^m\ 1^s$; Decl. —47° 32′.7

(9.3 . . . 10.0)

1913.819	261.8	1.42	....	400
.833	261.1	1.28	2.2	400
1913.83	261.5	1.35		

Innes 49. C.P.D. —53° 228

R.A. $0^h\ 55^m\ 11^s$; Decl. —53° 15′.3

(8.5 . . . 8.5)

1914.684	53.2	0.61	22.7	450

h 3430. C.P.D. —57° 292

R.A. $1^h\ 15^m\ 29^s$; Decl. —57° 59′.9

(7.5 . . . 10.0)

1914.882	236.6	2.43	4.9	450

h 3437. SD. —18° 234

R.A. $1^h\ 21^m\ 59^s$; Decl. —17° 54′.6

(9.0 . . . 9.3)

1912.850	156.8	8.87	23.5	300
.856	157.0	9.09	24.0	300
1912.85	156.9	8.98		

Dunlop 5. C.P.D. —56° 329

R.A. $1^h\ 35^m\ 3^s$; Decl. —56° 49′.7

(7.0 . . . 7.0)

1913.787	205.4	8.55	23.8	300

h 3473. C.P.D. — 52° 241

R.A. $1^h\ 51^m\ 7^s$; Decl. — 52° 13′.7
(5.0 . . . 10.0)

1914.756	196.6	5.79	23.0	360

Cordoba 4. C.P.D. — 52° 246

R.A. $1^h\ 52^m\ 50^s$; Decl. — 52° 48′.5
(8.2 . . . 10.0)

1914.756	42.5	3.35	23.3	450

Cordoba 6. C.P.D. — 45° 283

R.A. $2^h\ 46^m\ 21^s$; Decl. — 45° 45′.4
(9.1 . . . 9.3)

1912.850	2.2	3.29	23.8	300
.859	1.0	3.69	24.0	300
1912.85	1.6	3.49		

h 3550. C.P.D. — 51° 361

R.A. $3^h\ 0^m\ 38^s$; Decl. — 51° 48′.7
(7.5 . . . 8.0)

1914.756	78.9	38.57	0.7	370

Innes 55. C.P.D. — 44° 338

R.A. $3^h\ 8^m\ 2^s$; Decl. — 44° 53′.4
(A = 8.0, B = 8.5, C = 11.3)

	AB			
1912.850	168.5	0.91	0.0	300
.856	167.2	0.83	0.8	300
.859	171.2	0.85	0.1	300
1912.86	169.0	0.86		
	AB and C			
1912.850	210.4	3.06	0.1	300
.856	206.3	3.23	1.0	300
859	212.4	3.36	0.2	300
1912.86	209.7	3.22		

Innes 56. C.P.D. — 43° 353

R.A. $3^h\ 14^m\ 12^s$; Decl. — 43° 5′.9
(8.4 . . . 11.3)

1912.853	255.9	3.87	0.4	300
.856	256.3	4.11	1.6	300
.859	255.8	4.04	0.5	300
1912.86	256.0	4.01		

h 3576 = λ 24. C.P.D. — 46° 319

R.A. $3^h\ 20^m\ 24^s$; Decl. — 46° 6′.3
(7.7 . . . 9.2)

1912.850	342.4	3.23	0.4	300
.853	338.4	3.09	0.9	300
.859	340.0	3.14	0.9	300
1912.85	340.3	3.15		

Cf. Innes: Reference Catalogue, p. 24

h 3575. C.P.D. — 51° 404

R.A. $3^h\ 20^m\ 54^s$; Decl. — 51° 30′.3
(7.0 . . . 10.0)

1914.756	44.2	28.94	1.0	360

Sellors 5. C.P.D. — 48° 391

R.A. $3^h\ 37^m\ 59^s$; Decl. — 48° 38′.2
(7.7 . . . 9.2)

1912.894	184.9	1.72	0.8	300
.897	185.0	1.66	0.8	300
1912.90	185.0	1.69		

λ 31. C.P.D. — 48° 395

R.A. $3^h\ 42^m\ 28^s$; Decl. — 48° 16′.9
(8.5 . . . 12.0)

1912.894	76.4	7.84	1.1	300
.897	74.6	7.32	0.9	300
1912.90	75.5	7.58		

Dunlop 17. C.P.D. — 54° 616

R.A. $3^h\ 57^m\ 50^s$; Decl. — 54° 40′.4
(7.7 . . . 8.1)

1912.877	195.8	5.39	0.5	300
1913.718	193.1	5.44	1.1	300
.787	194.4	5.49	0.9	300
1913.46	194.4	5.44		

Innes 269. C.P.D. — 54° 618

R.A. $3^h\ 58^m\ 2^s$; Decl. — 54° 45′.3
(7.7 . . . 11.0)

1912.877	260.9	3.70	0.7	300
1913.787	261.6	3.45	1.0	300
1913.38	261.3	3.58		

Innes 271. C.P.D. — 43° 439

R.A. $4^h\ 17^m\ 43^s$; Decl. — 43° 5′.1
(7.7 . . . 10.4)

1912.853	142.8	2.69	1.6	300
.856	146.4	3.06	2.3	300
.859	142.2	2.69	1.3	300
1912.86	143.8	2.81		

Rumker 4. C.P.D. — 57° 659

R.A. $4^h\ 21^m\ 46^s$; Decl. — 57° 21′.2
(7.2 . . . 7.8)

1912.877	239.6	6.40	1.5	300
.951	238.6	6.42	2.4	300
1912.91	239.1	6.41		

Arequipa. C.P.D. —42° 513

R.A. $4^h\ 36^m\ 31^s$; Decl. —42° 6′.2
(4.5 . . . 12.0)

1912.859	115.4	6.69	1.6	300
.916	114.1	6.13	1.6	300
1912.89	114.7	6.36		

Innes 60. C.P.D. —45° 503

R.A. $4^h\ 37^m\ 21^s$; Decl. —45° 56′.8
(8.8 . . . 9.0)

1912.894	96.7	2.79	2.5	300
.897	97.1	2.55	1.8	300
.919	97.0	2.57	2.6	300
1912.90	96.9	2.64		

h 3683. C.P.D. —59° 370

R.A. $4^h\ 38^m 14^s$; Decl. —59° 11′.3
(7.5 . . . 8.0)

1914.920	263.4	0.91	1.6	450

Cordoba 9. C.P.D. —48° 530

R.A. $4^h\ 38^m\ 22^s$; Decl. —48° 3′.8
(7.6 . . . 10.0)

1912.894	234.3	3.78	2.1	300
.897	234.6	4.00	1.7	300
.919	230.3	3.77	2.7	300
1912.90	233.1	3.85		

Innes 342. C.P.D. —54° 718

R.A. $4^h\ 46^m\ 50^s$; Decl. —54° 6′.2
(8.2 . . . 8.6)

1912.935	163.6	1.42	2.5	300
.938	163.4	1.39	2.3	300
1912.94	163.5	1.41		

Innes 343. C.P.D. —54° 719

R.A. $4^h\ 47^m\ 8^s$; Decl. —54° 40′.1
(7.6 . . . 12.0)

1912.877	56.1	2.87	2.0	300
.932	50.5	2.20	2.7	300
.938	49.8	2.59	2.2	300
1912.92	52.1	2.55		

h 3715. C.P.D. —49° 611

R.A. $4^h\ 56^m\ 14^s$; Decl. —49° 38′.7
(7.5 . . . 9.2)

1912.845	112.5	9.87	....	300
.897	112.5	9.78	....	300
1912.87	112.5	9.83		

h 3739. C.P.D. —48° 618

R.A. $5^h\ 10^m\ 6^s$; Decl. —48° 1′.4
(8.4 . . . 9.0)

1912.845	280.0	3.24	....	300
.897	280.8	3.62	....	300
1912.87	280.4	3.43		

h 3767. C.P.D. —47° 595

R.A. $5^h\ 26^m\ 44^s$; Decl. —47° 10′.2
(5.5 . . . 12.0)

1912.845	250.2	25.84	2.3	300
.894	250.0	26.07	3.4	300
.897	250.4	25.86	2.8	300
1912.88	250.2	26.26		

Innes 62. C.P.D. —47° 596

R.A. $5^h\ 27^m\ 7^s$; Decl. —47° 17′.7
(8.9 . . . 9.5)

1912.894	176.8	0.96	3.3	300
.897	180.9	1.03	3.0	300
1912.90	178.9	1.00		

Dunlop 22. C.P.D. —42° 686

R.A. $5^h\ 27^m\ 17^s$; Decl. —42° 23′.7
(6.8 . . . 7.5)

1912.856	168.7	7.44	3.3	300
.859	169.9	7.44	2.4	300
1912.86	169.3	7.44		

h 3784. C.P.D. —46° 609

R.A. $5^h\ 34^m\ 40^s$; Decl. —46° 9′.7
(8.0 . . . 9.3)

1912.845	63.8	5.37	2.5	300
.894	64.1	5.37	3.5	300
.897	63.9	5.51	3.1	300
1912.88	63.9	5.42		

λ 55. C.P.D. —47° 645

R.A. $5^h\ 42^m\ 12^s$; Decl. —47° 25′.9
(8.5 . . . 10.2)

1912.845	308.5	1.27	2.6	300
1913.241	307.9	1.54	8.8	300
.244	308.4	1.44	8.6	300
1913.11	308.3	1.42		

Sellors 15. C.P.D. —61° 541

R.A. 5^h 52^m 4^s; Decl. —61° 51′.7
(7.3 . . . 8.3)

1914.956	319.4	0.62	2.4	450
.961	321.1	0.73	2.5	450
.964	319.5	0.68	4.1	450
1914.96	320.0	0.71		

λ 61. C.P.D. —44° 796

R.A. 6^h 4^m 54^s; Decl. —44° 20′.1
(6.5 . . . 13.0)

1912.916	121.3	33.34	3.0	300
1913.244	120.6	33.46	9.9	240
1913.08	121.0	33.40		

h 3846 = Cape 23. C.P.D. —49° 895

R.A. 6^h 11^m 10^s; Decl. —49° 4′.4
(8.7 . . . 9.8)

1912.845	62.9	4.83	3.1	300
.919	63.2	4.78	3.2	300
1912.88	63.0	4.80		

Innes 3. C.P.D. —61° 607

R.A. 6^h 11^m 14^s; Decl. —61° 26′.2
(7.0 . . . 8.0)

1914.956	4.2	0.75	2.5	450
.961	5.5	0.82	2.6	450
.964	1.3	0.74	4.0	450
1914.96	3.7	0.77		

Innes 156. C.P.D. —48° 856

R.A. 6^h 22^m 25^s; Decl. —48° 6′.3
(6.0 . . . 9.0)

1912.919	129.3	1.06	3.5	450
1913.241	128.7	1.28	9.3	670
.244	127.0	1.28	8.9	670
1913.13	128.3	1.21		

Cordoba. C.P.D. —48° 888

R.A. 6^h 32^m 33^s; Decl. —48° 10′.6
(7.5 . . . 9.2)

1912.845	201.6	10.88	3.6	300
.897	201.5	10.82	3.5	300
.919	202.3	10.88	3.7	300
1912.89	201.8	10.86		

Dunlop 31. C.P.D. —48° 907

R.A. 6^h 35^m 18^s; Decl. —48° 6′.5
(5.5 . . . 8.0)

1912.845	319.4	13.13	3.7	300
.897	319.9	13.00	3.6	300
.919	318.6	13.00	3.8	300
1912.89	319.3	13.04		

Innes 5. C.P.D. —61° 688

R.A. 6^h 36^m 40^s; Decl. —61° 25′.3
(7.0 . . . 8.8)

1914.956	271.1	2.70	3.9	360
.963	271.7	2.76	3.2	360
1914.96	271.4	2.73		

Innes 480. C.P.D. — 54° 1088

R.A. 6^h 40^m 25^s; Decl. — 54° 59′.5
(7.2 . . . 10.0)

1912.938	2.5	5.81	4.1	300
.951	0.0	5.79	3.0	300
1912.94	1.8	5.80		

Innes 6. C.P.D. —61° 706

R.A. 6^h 41^m 10^s; Decl. —61° 37′.7
(7.5 . . . 8.0)

1914.948	254.2	0.79	3.4	450
.956	253.6	0.75	4.0	450
1914.95	253.9	0.77		

h 3895. C.P.D. —47° 948

R.A. 6^h 43^m 21^s; Decl. —47° 40′.1
(7.0 . . . 10.0)

1912.845	63.5	26.41	3.9	300
.897	64.0	26.43	3.7	300
1912.87	63.8	26.42		

Innes 158. C.P.D. —48° 954

R.A. 6^h 44^m 3^s; Decl. —48° 25′.6
(7.5 . . . 10.5)

1912.919	182.6	1.62	3.9	450
1913.241	185.3	1.81	9.5	670
.244	189.1	1.77	9.0	670
1913.14	185.7	1.73		

Innes 157. C.P.D. — 54° 1015

R.A. 6^h 44^m 10^s; Decl. — 54° 33′.4
(7.0 . . . 9.5)

1912.938	338.8	1.72	4.3	450

Cape 19. C.P.D. —47° 999

R.A. $6^h\ 48^m\ 8^s$; Decl. —47° 36′.0
(9.2 . . . 9.5)

1912.897	300.5	2.04	3.9	300
.919	300.3	2.43	4.0	300
1913.241	301.7	2.43	9.7	670
1913.02	300.8	2.30		

Innes 483. C.P.D. —57° 1116

R.A. $7^h\ 1^m\ 4^s$; Decl. —57° 18′.9
(8.8 . . . 11.0)

1912.938	32.9	11.27	4.7	300
.951	33.6	11.34	3.6	300
1913.028	33.6	11.36	4.5	300
1912.97	33.4	11.32		

Hargrave 9. C.P.D. — 56° 1265

R.A. $7^h\ 7^m\ 25^s$; Decl. —56° 10′.0
(8.3 . . . 9.7)

1912.938	220.4	1.69	4.8	450
.951	224.0	1.30	3.8	450
1913.028	220.4	1.47	4.3	450
1912.97	221.5	1.49		

h 3941. C.P.D. —60° 782

R.A. $7^h\ 7^m\ 41^s$; Decl. —60° 10′.6
(8.1 . . . 8.6)

1914.956	302.1	0.93	4.2	360
.964	301.8	0.94	4.9	450
1914.96	302.0	0.94		

Dunlop 41. C.P.D. — 55° 1174

R.A. $7^h\ 7^m\ 51^s$; Decl. —55° 22′.8
(7.7 . . . 7.7)

1912.938	227.1	7.11	4.4	300
.951	226.1	7.20	4.0	300
1913.028	226.9	7.05	4.2	300
1912.97	226.7	7.12		

Dunlop 41 = Rümker 5 = Ward 3

Sellors 22. C.P.D. —44° 1360

R.A. $7^h\ 10^m\ 33^s$; Decl. —44° 26′.7
(9.0 . . . 10.2)

1912.916	261.8	2.16	4.9	450
1913.244	262.6	1.88	11.5	670
1913.08	262.2	2.02		

Innes 7. C.P.D. —46° 1360

R.A. $7^h\ 13^m\ 54^s$; Decl. —46° 46′.2
(7.5 . . . 9.2)

1912.919	205.4	0.96	5.1	450
1913.241	210.5	0.88	9.8	670
.244	207.0	0.86	9.1	670
1913.13	207.6	0.90		

Sellors 23. C.P.D. —43° 1376

R.A. $7^h\ 16^m\ 59^s$; Decl. —43° 35′.4
(9.0 . . . 10.0)

1912.916	157.7	2.60	5.0	300
1913.020	157.0	2.38	5.5	300
1912.97	157.4	2.49		

λ 88. C.P.D. —56° 1442

R.A. $7^h\ 46^m\ 26^s$; Decl. —56° 5′.6
(6.8 . . . 12.2)

1912.938	180.5	6.89	5.4	300
.951	179.8	6.96	4.6	300
1912.94	180.2	6.92		

Cordoba 17. C.P.D. —54° 1401

R.A. $7^h\ 46^m\ 47^s$; Decl. —54° 45′.7
(7.5 . . . 9.0)

1912.935	56.5	4.27	5.0	300
.938	55.1	4.00	5.2	300
.951	55.7	4.00	4.3	300
1912.94	55.8	4.09		

Brisbane. C.P.D. —44° 2475

R.A. $8^h\ 14^m\ 48^s$; Decl. —44° 38′.7
(8.0 . . . 8.2)

1913.017	326.9	5.29	5.8	300
.028	327.7	5.42	5.4	300
.034	326.7	5.24	4.9	300
1913.03	327.1	5.32		

Dunlop 70. C.P.D. —44° 2668

R.A. $8^h\ 25^m\ 15^s$; Decl. —44° 18′.3
(6.2 . . . 8.0)

1912.916	352.3	4.87	5.6	300
1913.017	350.0	4.80	6.4	300
.028	352.9	4.73	5.7	300
1912.99	351.7	4.80		

Innes 168. C.P.D. —44° 2685

R.A. 8^h 26^m 26^s; Decl. —44° 18′.9
(7.0 . . . 10.5)

1913.017	76.6	3.53	6.5	300
.028	80.3	3.70	5.8	300
.034	73.4	3.58	5.5	300
.036	74.8	3.63	6.7	300
.088	74.9	3.55	5.2	300
1913.04	76.0	3.60		

Innes 315 = Innes 811. C.P.D. —42° 2827

R.A. 8^h 37^m 28^s; Decl. —42° 9′3
(9.3 . . . 9.7)

1913.017	168.5	0.90	7.0	450
.028	173.3	0.90	6.4	450
.034	175.0	1.08	6.5	450
.088	169.7	1.03	5.7	450
1913.04	171.6	0.98		

Jacob 5. C.P.D. —42° 2926

R.A. 8^h 42^m 4^s; Decl. —42° 6′.5
(8.0 . . . 9.5)

1913.028	310.0	2.28	6.5	300
.034	309.9	2.31	6.7	300
.088	309.6	2.50	5.8	300
1913.05	309.8	2.36		

Innes 317. C.P.D. —42° 3114

R.A. 8^h 50^m 40^s; Decl. —42° 59′.4
(8.2 . . . 9.0)

1913.020	302.0	2.21	6.0	300
.028	304.8	2.25	6.7	300
.036	303.0	2.15	6.6	300
1913.03	303.3	2.20		

Cordoba 20. C.P.D. —42° 3149

R.A. 8^h 52^m 36^s; Decl. —42° 46′.4
(7.7 . . . 9.5)

1913.020	49.9	3.26	6.1	300
.036	48.4	3.13	6.7	300
.088	48.4	3.29	6.2	300
1913.05	48.9	3.23		

h 4181. C.P.D. —54° 2020

R.A. 9^h 2^m 29^s; Decl. —54° 13′.8
(9.5 . . . 9.8)

1913.151	134.8	3.21	7.8	300
.157	133.3	2.91	6.6	300
1913.15	134.0	3.06		

Cordoba 21. C.P.D. —43° 3403

R.A. 9^h 5^m 22^s; Decl. —43° 40′.0
(8.0 . . . 9.0)

1912.916	49.4	2.69	6.9	300
1913.020	47.4	2.43	6.6	300
.036	50.6	2.75	7.0	300
.088	48.3	2.99	6.6	300
1913.02	48.9	2.72		

λ 110. C.P.D. —46° 3477

R.A. 9^h 7^m 18^s; Decl. —46° 22′.3
(9.0 . . . 9.0)

1913.020	53.8	1.15	6.8	300

Innes 11. C.P.D. —45° 3566

R.A. 9^h 10^m 43^s; Decl. —45° 2′.3
(6.5 . . . 7.0)

1913.020	280.4	0.95	7.1	450
.195	274.4	0.78	7.3	670
1913.11	277.4	0.87		

Innes 31. C.P.D. —56° 2266

R.A. 9^h 27^m 7^s; Decl. —56° 25′.9
(9.0 . . . 10.0)

1913.122	155.5	3.24	7.0	300
.144	155.4	3.20	7.6	300
1913.13	155.5	3.22		

Innes 836. C.P.D. —54° 2510

R.A. 9^h 33^m 32^s; Decl. —54° 22′.6
(8.8 . . . 11.0)

1913.122	203.1	2.50	6.8	300
.144	205.1	2.53	7.8	300
.151	201.8	2.55	8.2	300
1913.14	203.3	2.53		

Dunlop 81. C.P.D. —44° 4340

R.A. 9^h 49^m 22^s; Decl. —44° 41′.6
(6.0 . . . 8.5)

1913.020	240.9	5.39	7.6	300
.034	240.5	5.69	7.1	300
.036	241.9	5.46	7.3	300
1913.03	241.1	5.51		

Innes 499. C.P.D. —53° 3290

R.A. 10^h 1^m 25^s; Decl. —53° 59′.2
(8.0 . . . 10.0)

1913.110	305.3	2.15	7.6	300
.122	306.1	1.76	8.0	300
.144	302.7	1.91	8.2	300
1913.12	304.7	1.94		

λ 118 = Innes 850. C.P.D. — 54° 3352

R.A. 10h 10m 33s; Decl. — 54° 55′.8
(7.5 . . . 12.5)

1913.122	145.3	14.03	7.6	300

Russell 140. C.P.D. — 55° 3229

R.A. 10h 14m 26s; Decl. — 55° 23′.7
(8.0 . . . 9.0)

1913.107	279.6	3.67	7.6	300
.122	281.3	3.41	8.2	300
.144	278.9	3.60	8.3	300
1913.12	279.9	3.56		

Innes 208. C.P.D. — 43° 4636

R.A. 10h 18m 31s; Decl. — 43° 36′.6
(7.5 . . . 8.5)

1913.036	29.5	0.84	8.4	450

Dunlop 88. C.P.D. — 44° 4896

R.A. 10h 26m 37s; Decl. — 44° 25′.4
(6.0 . . . 6.3)

1913.020	218.4	13.39	8.6	300
.034	218.9	13.55	8.0	300
.036	218.5	13.47	6.0	300
1913.03	218.6	13.47		

Cordoba 24. C.P.D. — 57° 3472

R.A. 10h 30m 18s; Decl. — 57° 1′.9
(8.0 . . . 10.5)

1913.187	239.7	4.93	7.4	670
.297	239.2	5.14	14.2	670
1913.24	239.5	5.04		

Cordoba 25. C.P.D. — 44° 5033

R.A. 10h 37m 6s; Decl. — 44° 36′.4
(8.8 . . . 9.5)

1913.034	225.3	3.18	8.1	300
.036	225.9	3.06	8.5	300
.195	226.1	2.80	8.6	300
1913.09	225.8	3.01		

Innes 398. C.P.D. — 56° 3761

R.A. 10h 40m 46s; Decl. — 56° 39′.6
(9.2 . . . 9.5)

1913.187	234.6	4.60	8.0	300
.297	235.4	4.87	14.4	300
1913.24	235.0	4.74		

Innes 862. C.P.D. — 54° 4128

R.A. 10h 48m 30s; Decl. — 54° 36′.4
(8.8 . . . 9.5)

1913.107	10.2	2.38	8.1	300
.110	10.9	2.43	8.1	300
.122	10.5	2.47	8.6	300
1913.11	10.5	2.43		

Innes 863. C.P.D. — 54° 4208

R.A. 10h 53m 22s; Decl. — 54° 16.2
(9.0 . . . 9.2)

1913.107	318.4	1.37	8.2	300
.110	316.8	1.23	8.2	300
1913.11	317.6	1.30		

Innes 865. C.P.D. — 48° 3648

R.A. 10h 55m 0s; Decl. — 48° 39′.9
(8.5 . . . 10.0)

1913.487	288.1	2.57	14.4	300

Innes 875. C.P.D. — 54° 4427

R.A. 11h 11m 0s; Decl. — 54° 52′.5
(8.5 . . . 10.5)

1913.107	239.0	2.23	8.7	300
.151	235.3	2.47	9.4	300
1913.13	237.2	2.35		

λ 129. C.P.D. — 52° 4466

R.A. 11h 14m 8s; Decl. — 52° 47′.5
(7.6 . . . 11.8)

1914.967	7.1	6.68	8.4	360
.972	6.8	6.77	8.7	360
1914.97	7.0	6.73		

Russell 168. C.P.D. — 42° 5254

R.A. 11h 16m 32s; Decl. — 42° 16′.4
(9.0 . . . 9.5)

1913.020	307.6	3.20	8.9	300
.195	308.2	2.97	8.9	300
1913.11	307.9	3.09		

Gillis 165 = W. O. 112. C.P.D. — 60° 3159

R.A. 11h 30m 43s; Decl. — 60° 12′.1
(7.5 . . . 8.5)

1914.961	4.6	2.01	....	450
.964	5.7	1.92	8.4	360
1914.96	5.2	1.97		

Innes 890. C.P.D. — 54° 4744

R.A. $11^h\ 38^m\ 47^s$; Decl. — 54° 46′.1

(8.2 . . . 11.2)

1913.157	306.2	2.53	9.3	300
.184	309.3	2.59	9.6	300
.187	306.6	2.84	9.3	300
1913.18	307.4	2.65		

Cordoba. C.P.D. — 25° 4812

R.A. $11^h\ 39^m\ 2^s$; Decl. — 25° 32′.5

(8.5 . . . 9.0)

1913.277	275.2	4.88	9.8	300

Russell 179. C.P.D. — 57° 4970

R.A. $11^h\ 39^m\ 58^s$; Decl. — 57° 23′.5

(8.8 . . . 8.8)

1913.157	177.6	5.20	9.6	300
.184	177.3	5.05	9.8	300
.187	177.1	5.27	9.8	300
1913.18	177.3	5.17		

Innes 894. C.P.D. — 44° 5764

R.A. $11^h\ 51^m\ 26^s$; Decl. — 44° 38′.6

(9.2 . . . 9.6)

1913.238	197.8	1.25	9.4	300
.241	200.4	1.35	9.3	670
.487	200.7	1.20	15.1	300
1913.32	200.0	1.27		

W. O. 115. C.P.D. — 57° 5217

R.A. $11^h\ 57^m\ 22^s$; Decl. — 57° 2′.8

(8.2 . . . 9.5)

1913.107	245.2	1.86	10.0	300
.144	245.9	1.98	9.6	300
.151	244.4	2.06	9.7	300
1913.13	245.2	1.97		

Innes 423. C.P.D. — 44° 5866

R.A. $12^h\ 4^m\ 33^s$; Decl. — 44° 43′.7

(7.0 . . . 12.2)

1913.238	164.1	2.91	9.6	300
.241	163.9	2.92	9.5	300
1913.24	164.0	2.92		

Howe 20. C.P.D. — 23° 5474

R.A. $12^h\ 15^m\ 2^s$; Decl. — 23° 31′.6

(8.5 . . . 8.8)

1913.258	149.6	5.20	9.8	300
.277	148.6	5.26	10.4	300
1913.27	149.1	5.23		

Innes 903. C.P.D. — 43° 5774

R.A. $12^h\ 16^m\ 54^s$; Decl. — 43° 59′.9

(9.5 . . . 10.5)

1913.261	271.6	2.69	9.9	240

α Crucis. C.P.D. — 62° 2745

R.A. $12^h\ 19^m\ 38^s$; Decl. — 62° 24′.3

(3.0 . . . 3.5)

1914.964	118.1	5.14	9.2	360

Innes 219. C.P.D. — 55° 5115

R.A. $12^h\ 24^m\ 55^s$; Decl. — 55° 25′.7

(8.8 . . . 9.5)

1913.110	51.7	1.79	9.3	300
.122	55.6	1.67	9.5	300
.144	51.2	2.13	10.0	300
.151	49.4	2.13	10.1	300
1913.13	52.0	1.93		

W. O. 116. C.P.D. — 55° 5161

R.A. $12^h\ 31^m\ 7^s$; Decl. — 55° 14′.5

(7.2 . . . 8.8)

1913.116	194.0	1.91	9.6	300
.122	193.1	1.99	9.6	300
.144	192.9	1.94	10.3	300
1913.12	193.3	1.95		

Innes 908. C.P.D. — 24° 4902

R.A. $12^h\ 36^m\ 50^s$; Decl. — 24° 33′.2

(9.5 . . . 10.5)

1913.258	155.7	3.43	10.0	300
.277	153.7	3.46	10.5	300
1913.27	154.7	3.45		

N. Z. 31. C.P.D. — 45° 6031

R.A. $12^h\ 39^m\ 26^s$; Decl. — 45° 23′.4

(9.5 . . . 10.0)

1913.261	23.3	1.37	10.3	300

Cin. 74. C.P.D. — 23° 5710

R.A. $13^h\ 7^m\ 42^s$; Decl. — 23° 37′.3

(6.5 . . . 11.0)

1913.277	333.0	12.44	11.4	300

Innes 920. C.P.D. — 22° 5583

R.A. $13^h\ 11^m\ 16^s$; Decl. — 22° 50′.4

(8.5 . . . 11.2)

1913.258	222.8	1.32	10.7	300
.277	217.3	1.45	11.6	300
1913.27	220.0	1.39		

Innes 939. C.P.D. — 44° 6627

R.A. $13^h\ 56^m\ 16^s$; Decl. — 44° 0′.8
(A = 8.8, B = 8.8, C = 12.0)

A B

1913.261	144.2	0.76	11.3	670
.294	136.4	0.78	10.6	670
1913.28	140.3	0.77		

A B and C

1913.294	74.0	7.94	10.7	300

Innes 522 = Innes 940. C.P.D. — 23° 5832

R.A. $13^h\ 56^m\ 44^s$; Decl. — 23° 32′.6
(8.4 . . . 9.0)

1913.258	296.0	1.05	12.0	670
.277	299.6	0.83	11.8	670
1913.27	297.8	0.94		

λ 198 = Innes 942. C.P.D. — 43° 6429

R.A. $14^h\ 2^m\ 8^s$; Decl. — 43° 41′.2
(7.6 . . . 11.8)

1913.294	139.1	9.29	11.2	300
.624	135.8	8.67	18.1	300
1913.46	137.4	8.98		

Innes 943. C.P.D. — 44° 6671

R.A. $14^h\ 2^m\ 45^s$; Decl. — 44° 24′.9
(8.9 . . . 11.5)

1913.261	315.0	4.61	11.7	300
.294	316.2	4.60	11.1	300
1913.28	315.6	4.61		

Innes 402. C.P.D. — 44° 6770

R.A. $14^h\ 18^m\ 10^s$; Decl. — 44° 48′.8
(4.9)

1913.294. Appears round with power 670

Innes 958. C.P.D. — 24° 5466

R.A. $15^h\ 4^m\ 30^s$; Decl. — 24° 9′.8
(9.5 . . . 9.8)

1913.277	100.2	0.74	13.2	670

Sh 228. C.P.D. — 23° 6369

R.A. $16^h\ 18^m\ 5^s$; Decl. — 23° 9′.4
(4.5 . . . 6.0)

1913.277	171.2	3.60	13.8	670

Antares.

R.A. $16^h\ 21^m\ 45^s$; Decl. — 26° 9′.1
(1.0 . . . 8.0)

1913.439	270.6	3.24	15.3	300

Innes 995. C.P.D. — 45° 8203

R.A. $16^h\ 46^m\ 27^s$; Decl. — 45° 7′.6
(8.0 . . . 11.5)

1913.258	227.4	2.16	13.9	300
.294	230.4	2.43	13.4	300
.441	231.8	1.98	14.0	300
.709	231.3	....	20.3	300
1913.42	230.2	2.19		

W. O. 131. C.P.D. — 56° 7940

R.A. $16^h\ 50^m\ 42^s$; Decl. — 56° 21′.6
(7.0 . . . 9.0)

1914.695	128.2	2.06	21.2	450
.698	130.0	2.26	20.2	360
1914.70	129.1	2.16		

Innes 102. C.P.D. — 44° 8242

R.A. $16^h\ 58^m\ 20^s$; Decl. — 44° 16′.2
(7.5 . . . 10.0)

1913.709	138.1	4.93	20.7	300

Arequipa. C.P.D. — 44° 8358

R.A. $17^h\ 10^m\ 21^s$; Decl. — 44° 5′.2
(8.0 . . . 8.0)

1913.441	10.7	0.54	14.3	670

λ 328. C.P.D. — 50° 10093

R.A. $17^h\ 17^m\ 31^s$; Decl. — 50° 32′.1
(11.0 . . . 12.0)

1914.698	275.9	4.30	20.7	360

Innes 40. C.P.D. — 45° 8654

R.A. $17^h\ 22^m\ 33^s$; Decl. — 45° 56′.2
(6.0 . . . 10.0)

1913.709	209.9	18.03	21.5	300

Innes 603. C.P.D. — 45° 8680

R.A. $17^h\ 24^m\ 43^s$; Decl. — 45° 32′.0
(8.5 . . . 10.0)

1913.709	83.7	1.59	21.7	300

Pollock 4. C.P.D. — 53° 8731

R.A. $17^h\ 31^m\ 22^s$; Decl. — 53° 24′.0
(8.0 . . . 10.5)

1914.698	296.1	11.00	21.4	360

Hargrave 124. C.P.D. — 52° 10777

R.A. $17^h\ 32^m\ 2^s$; Decl. — 52° 43′.6
(9.0 . . . 10.0)

1914.698	125.5	5.11	21.2	360

h 4978. C.P.D. — 53° 8799

R.A. $17^h\ 40^m\ 18^s$; Decl. — 53° 34′.1
(6.5 . . . 10.5)

1914.698	268.0	12.40	21.7	360

h 4984. C.P.D. — 52° 10900

R.A. $17^h\ 42^m\ 40^s$; Decl. — 52° 26′.5

(8.0 . . . 10.5)

1914.698	9.5	12.47	21.8	360

h 4994. C.P.D. — 52° 10927

R.A. $17^h\ 47^m\ 16^s$; Decl. — 52° 10′.8

(9.0 . . . 9.5)

1914.698	210.2	14.09	22.0	360

h 5014. C.P.D. —43° 8434

R.A. $17^h\ 57^m\ 47^s$; Decl. — 43° 25′.6

(6.0 . . . 6.2)

1913.441	57.8	0.96	14.7	670
.710	55.2	1.27	22.5	300
1913.58	56.5	1.11		

Cordoba 51. C.P.D. — 42° 8379

R.A. $18^h\ 14^m\ 21^s$; Decl. — 42° 50′.1

(8.6 . . . 9.0)

1913.441	136.5	3.45	15.0	300
.710	135.8	3.36	22.7	300
1913.68	136.2	3.41		

Innes 250. C.P.D. — 42° 8453

R.A. $18^h\ 32^m\ 20^s$; Decl. — 42° 16′.6

(7.5 . . . 8.5)

1913.439	130.0	0.73	16.5	670
.441	130.3	0.69	15.3	670
.710	129.1	1.12	23.3	300
1913.53	129.8	0.85		

Pollock 7 = λ 366. C.P.D. — 42° 8570

R.A. $18^h\ 53^m\ 49^s$; Decl. — 42° 26′.4

(9.0 . . . 9.2)

1913.710	182.6	2.30	23.5	300
.792	182.5	2.38	23.0	300
1913.75	182.6	2.34		

λ 365. C.P.D. — 42° 8577

R.A. $18^h\ 54^m\ 29^s$; Decl. — 42° 48′.7

(9.2 . . . 9.5)

1913.710	79.2	4.44	23.6	300
.792	77.7	4.36	23.1	300
1913.75	78.5	4.40		

Dunlop 225. C.P.D. — 52° 11383

R.A. $19^h\ 2^m\ 36^s$; Decl. — 52° 0′.4

(A = 7.6, B = 8.2, C = 10.8)

	A B			
1914.698	71.9	70.52	22.1	360
	A C			
1914.698	79.7	29.66	22.2	360

Innes 643. C.P.D. — 56° 9135

R.A. $19^h\ 6^m\ 31^s$; Decl. — 56° 9′.0

(9.0 . . . 9.3)

1914.695	47.4	1.19	21.5	360

h 5104. C.P.D. — 51° 10202-3

R.A. $19^h\ 11^m\ 15^s$; Decl. — 51° 16′.8

(9.0 . . . 9.0)

1914.698	38.9	18.46	22.5	360

Innes 649. C.P.D. — 51° 11230

R.A. $19^h\ 15^m\ 25^s$; Decl. — 51° 40′.1

(9.0 . . . 10.0)

1914.698	274.9	2.06	22.7	360

Innes 120 and h 5141. C.P.D. — 62° 6108

R.A. $19^h\ 38^m\ 0^s$; Decl. — 62° 7′.0

(A = 7.5, B = 7.5, C = 10.4)

	A B			
1914.849	135.5	0.40	0.5	450
.852	132.5	0.45	0.0	450
1914.85	134.0	0.42		
	A B and C			
1914.849	342.6	19.69	0.6	360
.852	342.1	19.44	23.8	360
1914.85	342.4	19.57		

h 5140. C.P.D. — 65° 3825

R.A. $19^h\ 38^m\ 2^s$; Decl. — 65° 12′.9

(8.2 . . . 8.4)

1914.849	85.6	1.89	23.9	450
.852	84.3	1.99	23.7	360
1914.85	85.0	1.94		

Innes 122. C.P.D. — 42° 8921

R.A. $19^h\ 42^m\ 1^s$; Decl. — 42° 10′.2

(8.0 . . . 11.0)

1913.710	338.0	5.98	0.3	300
.792	337.5	5.37	0.1	300
1913.75	337.8	5.67		

h 5163. C.P.D. — 63° 4561

R.A. $19^h\ 53^m\ 57^s$; Decl. — 63° 24′.4

(7.6 . . . 8.0)

1914.852	252.5	1.72	0.4	360
.871	250.1	1.55	0.3	360
.873	251.9	1.67	0.3	360
1914.86	251.5	1.65		

h 5167. C.P.D. —63° 4566

R.A. $20^h\ 0^m\ 37^s$; Decl. —63° 58′.9
(7.2 . . . 9.0)

1914.849	34.0	7.34	1.4	360
.852	35.2	7.24	0.8	360
.871	35.4	7.23	0.2	360
.873	35.8	7.15	0.1	360
1914.86	35.1	7.24		

h 5171. C.P.D. —64° 4035

R.A. $20^h\ 3^m\ 12^s$; Decl. —64° 48′.0
(A = 6.8, B = 9.8, C = 9.5)

	A B			
1914.871	305.4	17.65	0.6	360
	A C			
1914.871	335.6	30.07	0.5	360

Innes 411. C.P.D. —62° 6150

R.A. $20^h\ 5^m\ 13^s$; Decl. —62° 32′.4
(8.4 . . . 9.1)

1914.849	290.6	0.75	1.2	360
.852	283.2	1.13	0.9	360
1914.85	286.8	0.94		

h 5185. C.P.D. —59° 7604

R.A. $20^h\ 10^m\ 23^s$; Decl. —59° 7′.0
(7.8 . . . 11.0)

1914.841	61.3	18.89	0.9	360
.844	60.7	18.70	23.3	360
.847	60.7	18.77	0.2	360
1914.84	60.9	18.79		

β 763. C.P.D. —42° 9065

R.A. $20^h\ 13^m\ 59^s$; Decl. —42° 26′.5
(6.0 . . . 7.0)

1912.705	228.0	....	....	670
1913.439	227.4	1.05	17.2	300
.710	226.7	1.08	0.7	300
.792	227.5	0.88	0.3	400
.819	224.7	0.98	23.9	400
1913.49	227.1	1.00		

h 5204. C.P.D. —45° 9966

R.A. $20^h\ 23^m\ 30^s$; Decl. —45° 46′.3
(7.8 . . . 8.5)

1912.705	35.2	6.03	....	300
1913.439	34.5	6.45	17.3	300
.710	34.2	6.45	1.1	300
1913.28	35.0	6.31		

Innes 41. C.P.D. —45° 9989

R.A. $20^h\ 27^m\ 51^s$; Decl. —45° 59′.3
(7.0 . . . 8.0)

1913.439	357.8	1.76	17.5	670
.710	360.0	1.77	1.1	300
.792	357.0	1.66	0.7	300
.819	359.6	1.91	0.5	400
1913.69	358.6	1.77		

Russell 323. C.P.D. —63° 4604

R.A. $20^h\ 30^m\ 32^s$; Decl. — 63° 8′.0
(8.8 . . . 10.5)

1914.912	315.3	3.02	0.8	360

Rumker 26. C.P.D. —62° 6180

R.A. $20^h\ 41^m\ 11^s$; Decl. —62° 53′.5
(6.0 . . . 6.5)

1914.852	93.0	2.58	1.5	450
.873	93.7	2.81	1.2	360
.912	93.3	2.78	0.9	360
1914.88	93.3	2.72		

Innes 18. C.P.D. —52° 11793

R.A. $20^h\ 46^m\ 3^s$; Decl. —52° 35′.1
(6.8 . . . 10.5)

1914.646	2.7	4.38	18.2	475
.649	2.7	4.05	18.3	360
.858	0.3	4.27	1.5	360
1914.73	1.9	4.23		

Innes 129. C.P.D. —59° 7652

R.A. $20^h\ 46^m\ 34^s$; Decl. —59° 44′.6
(8.5 . . . 10.0)

1914.841	7.9	2.02	1.8	360
.844	7.3	1.84	0.3	450
1914.84	7.6	1.93		

h 5302. C.P.D. —53° 10200

R.A. $21^h\ 48^m\ 6^s$; Decl. —53° 38′.3
(8.7 . . . 10.5)

1914.618	351.5	12.57	18.9	360

h 5309. C.P.D. —51° 11755

R.A. $21^h\ 48^m\ 58^s$; Decl. —51° 39′.6
(9.5 . . . 9.8)

1914.618	348.1	9.13	19.2	360
.640	348.0	9.06	19.1	360
1914.63	348.1	9.10		

Innes 669. C.P.D. —52° 11799

R.A. $20^h\ 50^m\ 38^s$; Decl. —52° 39′.0
(8.5 . . . 8.5)

1914.646	72.8	0.71	18.3	450

Innes 130. C.P.D. — 48° 10519

R.A. 20^h 55^m 31^s; Decl. — 48° 27′.2
(7.0 . . . 11.5)

1913.819	316.3	3.38	1.2	400
.833	317.4	3.19	0.2	400
1913.83	316.9	3.28		

h 5250. C.P.D. — 64° 4110

R.A. 21^h 5^m 5^s; Decl. — 64° 12′.1
(8.0 . . . 10.0)

1914.912	305.3	9.65	1.3	360

Russell 329. C.P.D. — 60° 7461

R.A. 21^h 9^m 19^s; Decl. — 60° 44′.0
(9.5 . . . 10.0)

1914.844	298.7	21.48	1.1	360

h 5256. C.P.D. — 60° 7464-5

R.A. 21^h 10^m 22^s; Decl. — 60° 49′.1
(8.8 . . . 8.9)

1914.844	152.1	27.13	1.3	360

Innes 126. C.P.D. — 57° 9665

R.A. 21^h 13^m 18^s; Decl. — 57° 30′.2
(9.5 . . . 9.8)

1913.828	78.3	1.69	1.1	400
.836	80.4	1.88	0.1	400
1913.83	79.4	1.79		

Innes 132. C.P.D. — 52° 11862

R.A. 21^h 14^m 20^s; Decl. — 52° 28′.2
(7.5 . . . 10.0)

1914.585	292.2	1.51	18.5	360
.646	291.0	1.46	18.4	475
1914.62	291.6	1.48		

Russell 332. Not in C.P.D.

R.A. 21^h 20^m 25^s±; Decl. — 60° 48′±
(10.5 . . . 11.5)

1914.844	333.9	14.01	1.8	360
.847	333.7	13.57	0.7	360
1914.85	333.8	13.79		

h 5270. C.P.D. — 60° 7481

R.A. 21^h 20^m 56^s; Decl. — 60° 45′.0
(7.8 . . . 11.2)

1914.844	54.9	27.42	1.7	360
.847	54.4	27.32	0.5	360
1914.85	54.7	27.37		

h 5286. C.P.D. — 58° 7886

R.A. 21^h 34^m 29^s; Decl. — 58° 27′.9
(8.4 . . . 10.0)

1914.847	87.8	8.21	1.2	360

Arequipa. C.P.D. — 62° 6277

R.A. 21^h 45^m 57^s; Decl. — 62° 28′.2
(6.9)

1914.920. Examined this star under favorable conditions with powers 360, 450, and 670. It appears perfectly round with all powers. Also examined the neighboring stars of magnitudes 7.3 and 7.4. They also appeared single.

Innes 381. C.P.D. — 57° 10027

R.A. 21^h 57^m 28^s; Decl. — 57° 4′.6
(8.5 . . . 10.0)

1913.831	109.4	1.67	2.9	400

h 5316. C.P.D. — 59° 7765

R.A. 21^h 58^m 18^s; Decl. — 59° 44′.1
(8.6 . . . 9.0)

1914.838	140.0	3.89	2.5	360
.841	139.2	3.73	2.7	360
.847	140.8	3.86	1.7	360
1914.84	140.0	3.83		

h 5317. C.P.D. — 59° 7773

R.A. 22^h 3^m 6^s; Decl. — 59° 26′.6
(8.8 . . . 9.3)

1914.841	99.3	14.59	2.8	360
.847	100.6	14.45	1.9	360
1914.84	100.0	14.52		

Innes 20. C.P.D. — 63° 4769

R.A. 22^h 9^m 10^s; Decl. — 63° 25′.9
(7.2 . . . 8.0)

1914.852	329.2	0.42	2.5	450
.873	330.2	0.53	2.7	450
.920	324.9	0.31	2.7	670
1914.88	328.1	0.42		

h 5323. C.P.D. — 61° 6640

R.A. 22^h 10^m 51^s; Decl. — 61° 25′.1
(8.5 . . . 8.7)

1914.841	204.0	26.44	3.0	360
.847	204.6	26.50	2.4	360
1914.84	204.3	26.47		

h 5327. C.P.D. — 65° 4027

R.A. 22^h 14^m 4^s; Decl. — 65° 46'.8

(9.5 . . . 10.5)

1914.912	128.8	25.71	2.4	360

Innes 383. C.P.D. — 58° 7954

R.A. 22^h 16^m 37^s; Decl. — 58° 25'.1

(6.0 . . . 12.0)

1914.847	237.1	81.15	2.7	360

h 5334. C.P.D. — 65° 4044

R.A. 22^h 18^m 25^s; Decl. — 65° 36'.0

(5.0 . . . 9.0)

1914.852	282.4	7.10	3.0	360
.873	282.3	7.24	2.9	360
1914.86	282.4	7.17		

h 5338. C.P.D. — 52° 12028

R.A. 22^h 20^m 39^s; Decl. — 52° 25'.4

(7.5 . . . 11.0)

1914.618	182.5	30.58	19.5	360
.640	182.6	30.13	19.5	360
.649	182.0	30.47	19.3	360
1914.64	182.4	30.39		

h 5348. C.P.D. — 59° 7821

R.A. 22^h 31^m 2^s; Decl. — 59° 27'.4

(7.3 . . . 9.5)

1914.841	274.3	4.33	3.3	360

h 5349. C.P.D. — 53° 10326

R.A. 22^h 31^m 24^s; Decl. — 53° 20'.4

(6.5 . . . 11.5)

1914.635	117.3	34.18	19.9	360
.646	118.5	33.44	19.3	360
.687	118.5	34.74	20.1	360
1914.66	118.1	34.12		

h 5354. C.P.D. — 58° 7981

R.A. 22^h 32^m 29^s; Decl. — 58° 29'.4

(8.8 . . . 9.0)

1914.841	75.6	21.46	3.2	360

Cordoba 64. C.P.D. — 46° 10486

R.A. 22^h 56^m 49^s; Decl. — 46° 50'.4

(8.0 . . . 9.0)

1913.833	108.9	3.63	1.5	300

Dunlop 246. C.P.D. — 51° 11908

R.A. 23^h 0^m 1^s; Decl. — 51° 21'.6

(6.5 . . . 7.5)

1914.618	258.1	8.68	20.2	360
.858	257.8	8.36	3.1	360
1914.74	258.0	8.52		

Dunlop 245 = Gillis 282. C.P.D. — 60° 7635

R.A. 23^h 1^m 2^s; Decl. — 60° 24'.5

(7.3 . . . 9.5)

1914.841	291.3	13.99	3.5	360

h 5392 = Russell 343. C.P.D. — 58° 8064

R.A. 23^h 11^m 16^s; Decl. — 58° 59'.0

(7.8 . . . 9.0)

1914.841	327.8	24.18	3.9	360

The angle given by Herschel is 17° and that of Russell 338°, from which it appears that there is a comparatively rapid change in angle, probably due to proper motion.

Dunlop 248. C.P.D. — 50° 11799

R.A. 23^h 13^m 48^s; Decl. — 50° 59'.3

(6.0 . . . 7.0)

1914.618	211.2	16.77	20.8	360

Dunlop 250. C.P.D. — 50° 11819

R.A. 23^h 20^m 13^s; Decl. — 50° 58'.1

(6.5 . . . 8.5)

1914.618	88.9	39.33	21.2	360

h 5425. C.P.D. — 61° 6769

R.A. 23^h 43^m 38^s; Decl. — 61° 47'.9

(10.0 . . . 11.0)

1914.841	175.3	13.81	4.8	360

Sellors 14. C.P.D. — 52° 12220

R.A. 23^h 43^m 58^s; Decl. — 52° 23'.8

(8.0 . . . 8.5)

1914.646	26.8	1.03	21.2	670

Cordoba 69. C.P.D. — 48° 11009

R.A. 23^h 57^m 33^s; Decl. — 48° 49'.4

(7.5 . . . 10.2)

1913.710	67.9	3.50	21.4	300
.819	65.9	3.33	4.3	400
1913.71	66.9	3.42		

Arequipa. C.P.D. — 49° 11858

R.A. 23^h 59^m 51^s; Decl. — 49° 46'.3

(5.8 . . . 10.5)

1914.767	174.6	5.49	22.2	360

OBSERVATIONS OF COMETS AND MINOR PLANETS

The observations given below of comets and minor planets having Ann Arbor mean time were made with the 12¼-inch refractor of the Observatory of the University of Michigan, and those having La Plata mean times were made with the 17-inch refractor of the Observatory of the National University of La Plata.

The filar micrometer used at Ann Arbor was made in 1907 by The Warner & Swasey Company for the 12¼-inch refractor. It is described in these Publications, Vol. I, page 13. The filar micrometer used at La Plata was made by P. Gautier, of Paris, for the 8.4-inch refractor of the La Plata Observatory, and remodeled in the Instrument Shop of that Observatory for temporary use on the 17-inch refractor. It is described in the first volume of the Publications of the La Plata Observatory.

Whenever the comparison stars were near enough the observations were made by direct micrometer measurements. Only a few of the observations were made by the method of transits.

A few of the observations made at Ann Arbor were reduced by Mr. Frank D. Urie, now of the Elgin Observatory, while he was an Assistant in the Observatory of the University of Michigan. All of the observations made at La Plata were reduced by Mr. B. H. Dawson, Astronomer in the Observatory of La Plata.

OBSERVATIONS OF COMET DANIEL, 1909 *a*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1909 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	LOG $p\Delta$ FOR δ
June 17	13ʰ 21ᵐ 1ˢ	1	15, 10	−2ᵐ 19ˢ.52	+0′ 54″.0	1ʰ 45ᵐ 24ˢ.70	+31° 46′ 29″.5	9.7038n	0.7494
18	13 34 7	2	12, 8	+1 20.03	−6 31.4	1 48 17.67	+33 11 16.5	9.7126n	0.7302
19	13 35 37	3	8, 8	+0 24.83	+0 18.2	1 51 14.51	+34 33 27.0	9.7201n	0.7194
20	14 7 12	4	8, 8	−0 36.46	+5 49.2	1 54 19.45	+35 55 36.1	9.7296n	0.6655
July 16	13 46 40	5	10, 8	−0 9.55	+3 17.7	3 37 47.06	+60 3 39.6	9.9400n	0.5127
23	13 52 52	6	8, 8	−0 48.89	+6 24.8	4 12 30.74	+63 43 7.2	9.9912n	0.4724

BY GEO. A. LINDSAY.

July 16	14ʰ 14ᵐ 5ˢ	4	8, 8	−0ᵐ 5ˢ.06	+4′ 7″.3	3ʰ 37ᵐ 42ˢ.00	+60° 7′ 46″.9	9.9194n	0.4944
23	14 21 44	6	8, 8	−0 42.07	+6 54.5	4 12 37.56	+63 43 36.9	9.9905n	0.3532

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	1ʰ 47ᵐ 44ˢ.66	−0ˢ.44	+31° 45′ 42″.3	−6″.8	Leiden A. G. Catalogue 698
2	1 49 38.13	−0.43	+33 17 54.7	−6.8	Leiden A. G. Catalogue 707
3	1 50 50.08	−0.40	+34 33 15.9	−7.1	Leiden A. G. Cataolgue 718
4	1 54 56.31	−0.40	+35 49 54.1	−7.2	Lund A. G. Catalogue 921
5	3 37 47.61	−0.55	+60 3 48.0	−8.4	Helsingfors-Gotha A. G. Catalogue 3168
6	4 13 20.12	−0.49	+63 36 50.9	−8.5	Helsingfors-Gotha A. G. Catalogue 3477

OBSERVATIONS OF COMET DELAVAN, 1913*f*

Made with the 17-Inch Refractor of La Plata Observatory.

by W. J. Hussey.

1913 La Plata M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	log pΔ for α	log pΔ for δ
Dec. 17	10h 34m 51s	1	8, 8	+0m 7s.85	−1′ 27″.0	3h 3m 19s.10	−7° 25′ 24″.2	9.1987	0.6110n
18	10 7 57	3	8, 8	−0 7.50	+0 2.9	3 2 26.30	−7 19 51.2	9.0528	0.6096n
20	9 38 8	4	8, 10	+0 17.46	+2 58.3	3 0 42.39	−7 8 15.7	8.8494	0.6107n
21	8 55 14	6	8, 8	−0 17.63	+0 53.6	2 59 52.47	−7 2 25.7	8.0017n	0.6111n
23	8 47 28	7	8, 8	−0 12.37	−2 51.8	2 59 2.01	−6 56 13.8	8.2142n	0.6126n
23	8 38 35	8	8, 8	+0 17.63	−0 9.3	2 58 12.57	−6 49 50.1	8.4007n	0.6142n
26	8 58 38	9	8, 8	+0 4.51	−1 30.4	2 55 48.09	−6 29 58.3	8.6759	0.6192n
30	10 33 42	11	8, 8	+0 19.72	−0 14.4	2 52 46.37	−6 1 9.2	9.4343	0.6388n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	3h 3m 7s.14	+4s.11	−7° 24′ 16″.5	+19″.3	Connected with * 2.
2	3 6 21.48	+4.12	−7 23 31.3	+19.2	Vienna-Ottakring A. G. Catalogue 728
3	3 2 29.69	+4.11	−7 21 13.3	+19.2	Connected with * 2.
4	3 0 20.84	+4.09	−7 11 33.1	+19.1	Connected with * 5.
5	3 0 5.94	+4.09	−7 12 2.3	+19.1	Vienna-Ottakring A. G. Catalogue 696
6	3 0 6.01	+4.09	−7 3 38.2	+18.9	Connected with * 5.
7	2 59 10.30	+4.08	−6 53 40.8	+18.8	Connected with * 8.
8	2 57 50.86	+4.08	−6 49 59.5	+18.8	Vienna-Ottakring A. G. Catalogue 685
9	2 55 39.53	+4.05	−6 28 46.5	+18.6	Connected with * 10.
10	2 55 53.22	+4.05	−6 25 26.1	+18.6	Vienna-Ottakring A. G. Catalogue 677
11	2 52 22.63	+4.02	−6 1 13.4	+18.6	Vienna-Ottakring A. G. Catalogue 664.

OBSERVATIONS OF COMET ZLATINSKY, 1914 *b*.

Made at Ann Arbor with the 12¼-Inch Refractor.

by W. J. Hussey

1914 Ann Arbor M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	log pΔ for α	log pΔ for δ
May 25	9h 35m 33s	1	8, 8	+0m 2s.11	+3′ 16″.2	6h 43m 43s.39	+36° 47′ 38″.4	9.7180	0.7620
26	8 53 4	2	8, 8	+0 8.58	+6 43.1	6 59 35.79	+34 1 25.3	9.7197	0.6952
26	9 19 37	3	8, 8	−0 28.24	+5 48.4	6 59 52.96	+33 58 20.4	9.7155	0.7305
28	9 29 6	4	8, 8	+2 21.26	+5 36.3	7 27 41.21	+28 11 4.9	9.6904	0.7420
30	9 18 19	5	8, 8	+0 8.31	−3 30.1	7 49 28.18	+22 44 14.0	9.6733	0.7350

MEAN PLACES FOR 1914.0 OF COMPARISON STARS

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	6h 43m 40s.59	+0s.69	+36° 44′ 11″.9	+10″.3	Lund A. G. Catalogue 3528
2	6 59 26.45	+0.76	−33 54 32.7	+9.5	Leiden A. G. Catalogue 2956
3	7 0 20.44	+0.76	+33 52 22.6	+9.4	Leiden A. G. Catalogue 2963
4	7 25 19.10	+0.85	+28 5 21.0	+7.6	Cambridge A. G. Catalogue 3997
5	7 49 18.95	+0.92	+22 47 38.5	+5.7	Berlin A. G. Catalogue 3167

OBSERVATIONS OF THE MINOR PLANET FLORA (8),

Made at Ann Arbor with the 12¼-Inch Refractor.

by W. J. Hussey

1909 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
Nov. 3	$9^h 58^m 52^s$	1	8, 8	$-0^m 30^s.52$	$-9'$ 10".4	$3^h 52^m 31^s.87$	$+9°12'$ 51".9	9.4985n	0.7055
11	9 44 54	3	8, 8	−0 13.43	−0 14.9	3 44 53.96	+8 59 53.9	9.4460n	0.6758
23	9 50 1	4	6, 7	−1 54.00	+6 23.1	3 32 21.98	+8 57 30.2	9.2379n	0.6893
27	8 16 10	5	8, 8	+0 44.94	−2 6.8	3 28 28.51	+9 2 6.5	9.4672n	0.7034

by Frank D. Urie.

1909 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
Nov. 3	$10^h 23^m 32^s$	1	8, 8	$-0^m 31^s.45$	$-9'$ 9".0	$3^h 52^m 30^s.94$	$+9°12'$ 52".3	9.4473n	0.6989
8	11 33 1	2	8, 8	−1 31.05	+4 50.8	3 47 49.95	+9 3 49.2	9.1293n	0.6843
11	10 15 42	3	8, 6	−0 14.79	−0 16.9	3 44 52.60	+8 59 51.9	9.3635n	0.6944
13	10 14 43	3	12, 8	−2 18.24	−2 16.9	3 42 49.16	+8 57 51.9	9.3667n	0.6947
27	8 28 26	5	8, 8	+0 44.54	−2 3.1	3 28 28.11	+9 2 10.2	9.4395n	0.7001
29	8 26 31	5	10, 8	−1 8.20	+1 26.7	3 26 35.38	+9 5 39.9	9.3935n	0.6958
30	9 20 42	5	8, 8	−2 4.31	+3 35.1	3 25 39.28	+9 7 48.3	9.2155n	0.6865

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	Red. to app. pl.	δ	Red. to app. pl.	Authority
1	$3^h 52^m 59^s.48$	$+2^s.91$	$+9°21'$ 48".3	+14".0	Leipzig II A. G. Catalogue 1457
2	3 49 18.04	+2.96	+8 58 44.8	+13.6	Leipzig II A. G. Catalogue 1436
3	3 45 4.39	+3.00	+8 59 55.3	+13.5	Leipzig II A. G. Catalogue 1409
4	3 34 12.87	+3.11	+8 50 53.0	+14.1	Leipzig II A. G. Catalogue 1338
5	3 27 40.42	+3.15	+9 3 59.5	+13.8	Leipzig II A. G. Catalogue 1299

Reduction to app. pl. of * 3 for Nov. 13 is $+3^s.01$, + 13".5
Reduction to app. pl. of * 5 for Nov. 29 is + 3.16, + 13.7
Reduction to app. pl. of * 5 for Nov. 30 is + 3.17, + 13.7

OBSERVATIONS OF COMET DELAVAN, 1913 *f*.

Made at Ann Arbor with the 12¼-Inch Refractor.

by Bernhard H. Dawson

1914 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
Oct. 21	$6^h 52^m 43^s$	1	10, 8	$+1^m 21^s.11$	$-1'$ 25".1	$13^h 51^m 55^s.73$	$+30°18'$ 36".2	9.687	0.773
26	6 36 12	2	10, 10	−0 38.09	+6 15.7	14 12 8.66	+26 26 44.9	9.679	0.764
Nov. 1	6 22 32	3	8, 8	−0 17.24	+4 37.1	14 33 30.99	+21 54 56.5	9.667	0.763

MEAN PLACES OF COMPARISON STARS.

*	α 1914.0	Red. to app. pl.	δ 1914.0	Red. to app. pl.	Authority
1	$13^h 50^m 33^s.28$	$+1^s.34$	$+30°20'$ 15".9	−14".6	A. G. Leiden 5040
2	14 12 45.38	+1.37	+26 20 44.0	−14.8	A. G. Cambridge E. 6774
3	14 33 46.81	+1.42	+21 50 34.1	−14.7	A. G. Berlin B. 5119

OBSERVATIONS OF COMET WESTPHAL-DELAVAN, 1913*d*.

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY

1913 LA PLATA M. T.		*	COMP.	Δα	Δδ	APP. α	APP. δ	LOG pΔ FOR α	LOG pΔ FOR δ
Sept. 26	$10^h 29^m 7^s$	1	8, 8	$-0^m 13^s.17$	$-0'$ 15″6	$21^h 54^m 18^s.36$	$-$ 2° 34′ 27″.4	9.0654	0.6709n
27	8 15 26	3	8, 8	−0 4.00	−0 49.2	21 51 20.61	− 1 48 17.5	9.1682n	0.6802n
28	11 25 38	5	8, 8	−0 10.01	−1 32.8	21 47 40.24	− 0 50 17.9	9.4042	0.6917n
30	9 40 25	7	8, 8	−0 9.05	−2 16.7	21 41 34.75	+ 0 49 1.2	8.8718	0.7083n
Oct. 1	10 48 43	8	8, 8	−0 3.79	−0 56.5	21 38 20.63	+ 1 43 4.4	9.3518	0.7157n
2	12 21 48	10	8, 8	−0 0.14	−4 58 8	21 35 7.24	+ 2 37 51.5	9.5852	0.7162n
3	8 36 52	12	8, 8	−0 1.44	−4 1.3	21 32 37.78	+ 3 21 17.4	8.1900n	0.7341n
4	8 23 51	15	8, 8	−0 0.12	+1 30.3	21 29 44.61	+ 4 12 4.2	8.4543n	0.7421n
5	11 24 48	17	8, 8	−0 19.20	−2 37.4	21 26 31.44	+ 5 9 25.4	9.5242	0.7369n
15	9 12 20	18	8, 8	+0 8.51	+2 10.9	21 2 22.27	+13 10 58.1	9.3428	0.8028n
16	8 0 55	20	8, 8	+0 12.72	−1 16.2	21 0 26.96	+13 54 16.8	8.9353	0.8176n
17	8 5 52	22	8, 9	+0 11.68	+0 54.4	20 58 29.08	+14 39 29.2	9.0399	0.8214n
18	8 19 21	24	8, 8	−0 16.60	−3 11.9	20 56 35.50	+15 24 19.0	9.1781	0.8233n
18	8 49 45	25	8, ..	−2 25.69	....	20 56 33.23	....	9.3276	....
19	8 22 22	27	8, 8	+0 1.16	+2 41.5	20 54 47.03	+16 8 10.5	9.2291	0.8261n
19	8 59 39	28	8, 8	+0 12.28	+3 0.9	20 54 43.89	+16 9 16.1	9.3873	0.8173n
20	8 14 30	29	8, 8	+0 1.85	+0 59.1	20 53 4.05	+16 51 6.2	9.2187	0.8306n
24	8 16 45	31	8, 8	+0 8.81	+1 7.9	20 46 54.71	+19 37 46.0	9.3385	0.8396n
26	8 43 8	33	8, 8	−0 3.22	+3 39.4	20 44 14.62	+20 58 19.3	9.4656	0.8330n
27	8 20 36	36	8, 8	−0 5.08	−0 10.7	20 43 3.01	+21 36 46.7	9.4150	0.8424n
28	8 13 56	37	8, 9	−0 4.41	−0 27.1	20 41 54.56	+22 15 19.7	9.4117	0.8457n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	$21^h 54^m 28^s.07$	$+3^s.46$	− 2° 34′ 27″.7	+15″.9	Connected with * 2
2	21 58 48.83	+3.46	− 2 34 32.8	+16.2	Strassburg A. G. Catalogue 7695
3	21 51 21.19	+3.42	− 1 47 44.1	+15.8	Connected with * 4
4	21 54 53.16	+3.43	− 1 47 49.6	+16.0	Strassburg A. G. Catalogue 7678
5	21 47 46.88	+3.37	− 0 49 0.8	+15.7	Connected with * 6
6	21 50 52.06	+3.38	− 0 53 53.4	+15.9	Nicolajew A. G. Catalogue 5529
7	21 41 40.51	+3.29	+ 0 51 2.3	+15.6	Nicolajew A. G. Catalogue 5509
8	21 38 21.17	+3.25	+ 1 43 45.3	+15.6	Connected with * 9
9	21 35 20.23	+3.24	+ 1 44 44.4	+15.4	Albany A. G. Catalogue 7567
10	21 35 4.17	+3.21	+ 2 42 34.7	+15.6	Connected with * 11
11	21 36 9.29	+3.21	+ 2 47 17.5	+15.7	Albany A. G. Catalogue 7573
12	21 32 36.04	+3.18	+ 3 25 3.0	+15.7	Connected with * 13
13	21 32 36.06	+3.18	+ 3 30 48.6	+15.7	BD. + 3°4584. Connected with * 14
14	21 36 25.19	+3.19	+ 3 30 5.9	+16.0	Albany A.G. Catalogue 7576
15	21 29 41.59	+3.14	+ 4 10 18.2	+15.7	Connected with * 16
16	21 28 48.58	+3.14	+ 4 10 38.8	+15.7	Albany A. G. Catalogue 7535
17	21 26 47.53	+3.11	+ 5 11 47.1	+15.8	Albany A. G. Catalogue 7527
18	21 2 11.08	+2.68	+13 8 30.9	+16.3	Connected with * 19
19	21 4 14.39	+2.69	+13 4 16.4	+16.4	Leipzig A. G. Catalogue 8349
20	21 0 11.60	+2.64	+13 55 16.6	+16.4	Connected with * 21
21	20 59 57.04	+2.63	+14 1 39.1	+16.4	Leipzig A. G. Catalogue 8312
22	20 58 14.80	+2.60	+14 38 18.3	+16.5	Connected with * 23
23	20 56 48.36	+2.59	+14 42 54.8	+16.4	Leipzig A. G. Catalogue 8276
24	20 56 49.54	+2.56	+15 27 14.2	+16.5	Connected with *'s 25 and 26
25	20 58 56.34	+2.58	+15 25 0.4	+16.8	Berlin A. G. Catalogue 8562
26	20 58 10.83	+2.57	+15 25 10.7	+16.8	Berlin A. G. Catalogue 8550
27	20 54 43.35	+2.52	+16 5 12.2	+16.8	Berlin A. G. Catalogue 8512
28	20 54 29.09	+2.52	+16 5 58.4	+16.8	Berlin A. G. Catalogue 8510
29	20 52 59.71	+2.49	+16 49 50.2	+16.9	Connected with * 30
30	20 52 59.56	+2.49	+16 45 44.5	+16.9	Berlin A. G. Catalogue 8493
31	20 46 43.54	+2.36	+19 36 21.0	+17.1	Connected with * 32
32	20 46 5.14	+2.36	+19 35 25.0	+17.1	Berlin A. G. Catalogue 8420
33	20 44 15.60	+2.24	+20 54 22.6	+17.3	Connected with * 34
34	20 44 29.49	+2.24	+20 54 40.4	+17.3	Berlin A. G. Catalogue 7940
35	20 43 5.89	+2.20	+21 36 40.1	+17.3	Connected with * 36
36	20 43 16.55	+2.20	+21 39 29.0	+17.3	Berlin A. G. Catalogue 7929
37	20 41 56.81	+2.16	+22 15 29.4	+17.4	Berlin A. G. Catalogue 7924

OBSERVATIONS OF COMET MOREHOUSE, 1908 *c*.

Made at Ann Arbor with the 12¼-Inch Refractor.

by W. J. Hussey

1908 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
Sept. 4	$10^h\ 5^m\ 22^s$	1	11, 8	$+3^m\ 51^s.14$	$-1'\ 29''.2$	$3^h\ 15^m\ 16^s.95$	$+67°\ 57'\ 16''.5$	0.0629	0.4109
5	9 40 16	2	8, 9	−0 20.92	−6 27.1	3 11 20.67	+68 31 38.0	0.0747	0.4765

MEAN PLACES FOR 1908.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$3^h\ 11^m\ 22^s.62$	$+3^s.19$	$+67°\ 58'\ 54''.1$	$-8''.4$	Christiania A. G. Catalogue 567
2	3 11 38.23	+3.36	+68 38 13.5	−8.4	Connected with * 3. $\Delta\alpha = +0^m 37^s.16$, $\Delta\delta = -11' 37''.6$
3	3 11 1.07	+3.36	+68 49 51.1	−8.4	Christiania A. G. Catalogue 564

OBSERVATIONS OF THE MINOR PLANET FORTUNA (19),

Made at Ann Arbor with the 12¼-Inch Refractor.

by W. J. Hussey.

1909 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
July 16	$12^h\ 7^m\ 9^s$	1	8, 8	$-0^m\ 4^s.17$	$+9'\ 30''.1$	$19^h\ 59^m\ 41^s.93$	$-17°\ 52'\ 54''.5$	8.4724n	0.8809
16	12 53 1	3	8, 8	−0 45.40	+4 28.0	19 59 40.38	−17 52 59.3	8.7907	0.8802
24	12 25 15	7	8, 8	+0 12.22	−4 48.0	19 51 40.56	−18 14 28.2	9.2993	0.8710

by Geo. A Lindsay.

July 16	$12^h\ 29^m\ 15^s$	1	8, 8	$-0^m\ 5^s.15$	$+9'\ 28''.9$	$19^h\ 59^m\ 40^s.95$	$-17°\ 52'\ 55''.7$	8.1557	0.8817
19	12 42 11	4	8, 8	+0 19.32	−6 41.1	19 56 41.62	−18 1 0.9	8.8327	0.8805
21	12 40 50	6	19, 8	+0 50.02	+5 57.1	19 54 40.71	−18 6 19.6	8.8928	0.8801
23	11 31 8	6	20, 8	−1 7.64	+0 36.8	19 52 43.05	−18 11 39.9	8.5157n	0.8823

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$19^h\ 59^m\ 43^s.87$	$+2^s.23$	$-18°\ 2'\ 29''.0$	$+4''.4$	8.9 mag. Connected with * 2
2	19 57 16.62	+2.23	−18 9 28.1	+4.4	Kam₁ 3927
3	20 0 23.54	+2.24	−17 57 31.8	+4.5	Washington Zones 18836
4	19 56 20.03	+2.27	−17 54 24.1	+4.3	9.5 mag. Connected with * 5
5	19 56 38.33	+2.27	−17 48 7.1	+4.3	Washington A. G. Catalogue 7523
6	19 53 48.40	+2.29	−18 12 20.9	+4.2	Radcliffe₃ 5342
7	19 51 26.04	+2.30	−18 9 44.0	+3.8	Weisse Argelander 15791

OBSERVATIONS OF COMET NEUJMIN, 1913 *c*.

Made at La Plata with the 17-Inch Refractor.

by W. J. Hussey.

1913 La Plata M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	log pΔ for α	log pΔ for δ
Sept. 9	$12^h\ 9^m\ 0^s$	1	8, 8	$+0^m\ 8^s.79$	$-1'\ 52''.7$	$23^h 48^m\ 5^s.46$	$+0°56'\ 57''.6$	8.6976n	0.7098n
9	12 26 26	2	8, 8	+0 12.20	−3 35.1	23 48 5.01	+0 57 36.8	8.1821n	0.7099n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$23^h 47^m 53^s.19$	$+3^s.48$	$+0°58'\ 28''.2$	$+22''.1$	Connected with * 2
2	23 47 49.33	+3.48	+1 0 49.8	+22.1	Nicolajew A. G. Catalogue 5901

OBSERVATIONS OF THE MINOR PLANET HESTIA (46),

Made at Ann Arbor with the 12¼-Inch Refractor.

by W. J. Hussey

1909 Ann Arbor M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	log pΔ	
July 9	$11^h 52^m 22^s$	1	8, 8	$-0^m 38^s.60$	$+7'\ 10''.9$	$18^h 22^m 12^s.57$	$-19°23'\ 37''.6$	8.9049	0.8858
10	11 12 23	2	8, 8	−0 11.95	+3 9.2	18 21 17.71	−19 24 35.2	7.9851	0.8877
12	11 45 22	3	8, 8	+0 42.04	−0 18.6	18 19 25.31	−19 26 47.0	8.9782	0.8849
15	11 15 26	5	8, 8	−0 14.39	+2 43.0	18 16 46.51	−19 30 00.1	8.8101	0.8869
16	11 01 16	6	8, 8	+0 8.23	+2 3.3	18 15 55.71	−19 31 6.4	8.6606	0.8875
18	10 16 51	8	8, 8	−0 25.61	−0 50.8	18 14 18.13	−19 33 25.5	8.3908n	0.8881
19	11 41 6	9	8, 8	−0 12.26	−5 9.8	18 13 27.78	−19 34 46.0	9.1824	0.8815

by Geo. A. Lindsay.

July 9	$12^h 19^m 22^s$	1	8, 8	$-0^m 39^s.57$	$+7'\ 14''.0$	$18^h 22^m 11^s.60$	$-19°23'\ 34''.5$	9.1248	0.8829
12	12 7 41	3	8, 8	+0 41.25	−0 19.7	18 19 24.52	−19 26 48.1	9.1428	0.8782
14	11 19 2	4	8, 8	−0 26.22	−5 7.0	18 17 38.26	−19 28 54.7	8.7881	0.8787
15	11 32 7	5	8, 8	−0 14.97	+2 41.2	18 16 45.93	−19 30 1.9	8.9788	0.8854
16	11 16 29	6	8, 8	+0 7.69	+2 2.6	18 15 55.17	−19 31 7.1	8.8704	0.8867
19	10 15 14	9	8, 8	−0 9.30	−5 6.5	18 13 30.74	−19 34 42.7	8.3217n	0.8883
21	10 25 49	10	8, 8	−0 19.93	+5 16.0	18 11 59.01	−19 37 4.1	8.3278	0.8884

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$18^h 22^m 49^s.03$	$+2^s.14$	$-19°30'\ 47''.9$	$-0''.6$	Weiss's Argelander 14395
2	18 21 27.52	+2.14	−19 27 43.8	−0.6	Connected with * 1. $\Delta\alpha = -1^m 21^s.51$, $\Delta\delta = +3' 4''.1$.
3	18 18 41.12	+2.15	−19 26 27.7	−0.7	Radcliffe₃ 4811
4	18 18 2.31	+2.17	−19 23 47.0	−0.7	Connected with * 3. $\Delta\alpha = -0^m 38^s.81$, $\Delta\delta = +2' 40''.7$.
5	18 16 58.73	+2.17	−19 32 42.5	−0.6	Connected with * 3. $\Delta\alpha = -1^m 42^s.39$, $\Delta\delta = -6' 14''.8$.
6	18 15 45.29	+2.19	−19 33 8.9	−0.8	Connected with * 7. $\Delta\alpha = +0^m 7^s.18$, $\Delta\delta = +8' 42''.3$.
7	18 15 38.11	+2.19	−19 41 51.2	−0.8	Weiss's Argelander 14267
8	18 14 41.55	+2.19	−19 32 33.8	−0.9	Weiss's Argelander 14250
9	18 13 37.85	+2.19	−19 29 35.2	−1.0	Weiss's Argelander 14222
10	18 12 16.76	+2.18	−19 42 19.0	−1.1	Radcliffe₃ 4777

OBSERVATION OF COMET CAMPBELL, 1914 *e*.

Made at Ann Arbor with the 12¼-Inch Refractor.

by Bernhard H. Dawson.

1914 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for δ	for α
1914 Nov. 7	$7^h 4^m 23^s$	1	10, 10	$+0^m 23^s.10$	$+1'\ 9''.4$	$21^h 46^m 35^s.68$	$+6°\ 6'\ 13''.0$	8.646	0.713

MEAN PLACES OF COMPARISON STARS.

*	α 1914.0	Red. to App. Pl.	δ 1914.0	Red. to App. Pl.	Authority
1	$21^h 46^m\ 9^s.47$	$+3^s.11$	$+6°\ 4'\ 43''.8$	+19.8	Connected with *'s 2 and 3
2	21 44 21.02	+3.09	+6 4 30.8	+19.7	A. G. Leipzig II 10949
3	21 48 11.11	+3.12	+6 5 31.0	+20.0	A. G. Leipzig II 10990

OBSERVATIONS OF COMET, 1910 *a*.

Made at Ann Arbor with the 12¼-Inch Refractor.

by W. J. Hussey

1910 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	for δ
Jan. 24	$5^h 58^m 31^s$	1	8, 8	$-0^m 16^s.60$	$+13'\ 42''.1$	$21^h 13^m\ 9^s.25$	$-4°40'\ 21''.2$	9.6421	0.7788
31	6 26 24	2	5, 3	−3 54.07	− 0 25.6	21 36 8.82	+2 34 7.2	9.6353	0.7669
Feb. 3	6 32 35	3	8, 5	+0 18.20	− 6 48.1	21 42 46.09	+4 29 58.9	9.6383	0.7659
4	6 15 53	5	8, 8	+0 9.10	+ 7 59.1	21 44 39.35	+5 0 34.5	9.6367	0.7632
4	6 24 15	6	8, 8	+0 18.09	+ 3 9.0	21 44 39.80	+5 0 40.1	9.6376	0.7641
6	6 28 42	7	8, 8	+0 15.70	− 3 45.3	21 48 12.99	+6 0 17.8	9.6397	0.7644
7	6 22 15	8	8, 8	+0 25.35	+ 1 23.2	21 49 51.51	+6 27 35.1	9.6396	0.7628

MEAN PLACES FOR 1910.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$21^h 13^m 27^s.78$	$-1^s.93$	$-4°53'\ 52''.6$	$-10''.7$	Strassburg A. G. Catalogue 7432
2	21 40 4.77	−1.88	+2 34 43.5	−10.7	Albany A. G. Catalogue 7593
3	21 42 29.76	−1.87	+4 36 57.7	−10.7	9.3 mag. Connected with *4. $\Delta\alpha = -13^s.43$, $\Delta\delta = -4'44''.8$.
4	21 42 43.19	−1.87	+4 41 42.5	−10.7	Albany A. G. Catalogue 7602
5	21 44 32.11	−1.86	+4 52 46.1	−10.7	Albany A. G. Catalogue 7614
6	21 44 23.57	−1.86	+4 57 41.8	−10.7	Albany A. G. Catalogue 7613
7	21 47 59.13	−1.84	+6 4 13.8	−10.7	Leipzig A. G. Catalogue 10990
8	21 49 27.99	−1.83	+6 26 22.6	−10.7	Leipzig A. G. Catalogue 11000

OBSERVATIONS OF COMET METCALF, 1910*b*

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1910 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	LOG $p\Delta$ FOR δ
Oct. 7	$7^h 48^m 56^s$	1	8, 8	$-0^m 12^s.41$	$-0'\ 50''.3$	$15^h 25^m 59^s.67$	$+18° 19' 34''.5$	9.6561	0.7234
8	7 54 53	1	8, 8	−0 7.78	+2 38.9	15 26 4.30	+18 23 3.5	9.6577	0.7274
9	8 26 1	1	8, 8	−0 2.05	+6 19.6	15 26 10.02	+18 26 44.0	9.6606	0.7548
10	7 43 44	3	8, 8	−0 37.26	−3 29.1	15 26 16.07	+18 30 16.1	9.6581	0.7273
11	7 25 11	3	8, 8	−0 30.07	+2 41.9	15 26 35.80	+18 42 1.8	9.6543	0.7154

MEAN PLACES FOR 1910.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	$15^h 26^m 11^s.74$	$+0^s.34$	$+18° 20' 24''.7$	$+0''.1$	9.5 mag. Connected with *2. $\Delta\alpha = +1^m 47^s.95$; $\Delta\delta = +0' 49''.5$.
2	15 24 23.79	+0.34	+18 19 35.3	+0.0	Berlin A. G. Catalogue 5554
3	15 26 53.00	+0.33	+18 33 45.6	−0.4	9.3 mag. Connected with *4. $\Delta\alpha = -0^m 12^s.54$; $\Delta\delta = -5' 34''.9$.
4	15 27 5.54	+0.33	+18 39 20.5	−0.4	Berlin A. G. Catalogue 5567

Reduction to apparent place: *1 Oct. 8, $+0^s.34$, $-0''.2$; Oct. 9, $+0^s.33$, $-0''.3$.
*3 Oct. 11, +0.33, −0.6.

OBSERVATIONS OF COMET GALE, 1912*a*.

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY

1912 LA PLATA M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	LOG $p\Delta$ FOR δ
Sept. 17	$6^h 59^m 41^s$	1	10, 5	$+2^m 11^s.40$	$+3'\ 56''.5$	$14^h 26^m 58^s.47$	$-25°\ 5' 16''.7$	9.6819	0.5085n
19	6 53 46	2	10, 8	+0 24.47	−0 43.2	14 36 31.01	−22 15 23.5	9.6692	0.5347n
20	6 43 25	3	10, 8	−0 13.09	−2 3.0	14 40 59.41	−20 50 25.4	9.6499	0.5311n
20	7 12 19	3	8, 8	−0 7.91	−0 19.9	14 41 4.59	−20 48 42.3	9.6768	0.5669n

BY H. J. COLLIAU.

Sept. 20	7 30 55	3	8, 8	$-0^m\ 4^s.67$	$+0'\ 47''.5$	$14^h 41^m\ 7^s.83$	$-20° 47' 34''.9$	9.6900	0.5894n

MEAN PLACES FOR 1912.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED TO APP. PL.	AUTHORITY
1	$14^h 24^m 46^s.14$	$+0^s.93$	$-25°\ 8' 59''.4$	$-13''.8$	Cordoba General Catalogue 19614
2	14 36 5.53	+1.01	−22 14 27.1	−13.2	Cordoba General Catalogue 19885
3	14 41 11.46	+1.04	−20 48 9.5	−12.9	Cordoba General Catalogue 20010

OBSERVATIONS OF COMET ZINNER-GIACOBINI, 1913e

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY

1913 La Plata M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	Log pΔ for α	Log pΔ for δ
Oct. 28	8h 50m 19s	1	8, 8	−0m 11s.09	+0′ 37″.0	19h 6m 8s.75	− 9° 17′ 59″.0	9.6375	0.6442n
29	8 53 18	3	8, 8	−0 2.78	+0 51.1	19 11 12.74	−10 15 33.6	9.6406	0.6383n
30	8 48 27	5	8, 8	−0 18.33	−1 22.8	19 16 22.52	−11 13 40.4	9.6360	0.6279n
31	8 14 5	6	8, 8	+0 9.75	+2 53.8	19 21 32.63	−12 11 8.0	9.5939	0.5991n
31	8 48 52	7	11, —	−1 42.98	....	19 21 40.47	....	9.6366	....
Nov. 1	8 26 47	8	8, 8	+0 12.93	+1 32.0	19 27 0.89	−13 11 13.4	9.6109	0.5960n
1	9 3 58	9	14, —	+1 4.32	....	19 27 9.35	....	9.6503	....
2	7 48 32	10	8, 8	−0 13.04	+1 47.4	19 32 24.82	−14 9 46.2	9.5506	0.5586n
6	8 40 48	12	8, 8	+0 17.70	−3 34.0	19 56 4.85	−18 15 13.4	9.6277	0.5460n
8	8 49 44	13	8, 8	+0 14.12	−5 39.9	20 8 37.53	−20 17 15.0	9.6383	0.5269n
16	9 25 33	15	8, 8	−0 2.34	+3 28.9	21 3 44.02	−27 56 56.6	9.6782	0.4439n
18	8 32 53	17	8, 8	−0 0.68	−1 49.7	21 18 15.57	−29 35 53.1	9.6010	0.2740n
18	8 59 20	18	14, —	+1 41.17	....	21 18 23.80	....	9.6441	....
19	8 27 9	19	8, 8	+0 18.71	+2 37.4	21 25 46.29	−30 23 49.9	9.5870	0.2252n
29	9 34 4	21	8, 8	+0 22.18	−0 12.6	22 43 19.76	−36 18 35.8	9.6670	0.1281n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	19h 6m 17s.50	+2s.34	− 9° 18′ 35″.6	−0″.4	Connected with * 2
2	19 6 35.32	+2.34	− 9 15 39.7	−0.4	Vienna-Ottakring A. G. Catalogue 6607
3	19 11 13.14	+2.38	−10 16 24.4	−0.3	Connected with * 4
4	19 11 36.14	+2.38	−10 14 10.9	−0.3	Harvard A. G. Catalogue 6691
5	19 16 38.44	+2.41	−11 12 17.4	−0.2	Harvard A. G. Catalogue 6747
6	19 21 20.43	+2.45	−12 14 1.6	−0.2	Connected with * 7
7	19 23 20.99	+2.46	−12 19 10.2	−0.0	Harvard A. G. Catalogue 6802
8	19 26 45.48	+2.48	−13 12 45.3	−0.1	Connected with * 9
9	19 26 2.55	+2.48	−13 9 50.8	−0.1	Harvard A. G. Catalogue 6830
10	19 32 35.33	+2.53	−14 11 33.7	+0.1	Connected with * 11
11	19 32 54.44	+2.53	−14 9 7.0	+0.1	Washington A. G. Catalogue 7369
12	19 55 44.45	+2.70	−18 11 39.7	+0.3	Bordeaux 6023
13	20 8 20.62	+2.79	−20 11 35.6	+0.5	Connected with * 14
14	20 8 20.18	+2.79	−20 8 58.7	+0.5	Cincinnati Zone Catalogue 3359
15	21 3 43.19	+3.17	−28 0 27.5	+2.0	Connected with * 16
16	21 1 40.76	+3.16	−28 0 43.8	+1.8	Argentine General Catalogue 28937
17	21 18 12.98	+3.27	−29 34 5.9	+2.5	Connected with * 18
18	21 16 39.37	+3.26	−29 32 7.6	+2.4	Argentine General Catalogue 29281
19	21 25 24.27	+3.31	−30 26 30.0	+2.7	Connected with * 20
20	21 24 54.82	+3.31	−30 30 1.0	+2.6	Cordoba Zone Catalogue 703
21	22 42 53.91	+3.67	−36 18 29.0	+5.8	Connected with * 22
22	22 46 52.16	+3.69	−36 21 1.1	+6.0	Argentine General Catalogue 31110

OBSERVATIONS OF COMET CAMPBELL, 1904 *e*.

Made with the 17-Inch Refractor of La Plata Observatory.

by W. J. Hussey.

1914 La Plata M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
Sept. 24	$9^h\ 4^m\ 34^s$	1	8, 8	$+0^m\ 11^s.90$	$-1'\ 41''.1$	$0^h\ 38^m\ 44^s.30$	$-49°\ 2'\ 17''.0$	9.7610n	9.4431
24	9 20 22	2	8, 8	−0 6.15	−3 12.4	0 38 27.16	−49 0 13.9	9.7261n	9.6705
26	10 4 36	3	.. 2	....	+6 39.9	....	−42 14 50.0	....	9.8983
26	12 50 6	4	8, 8	+0 27.84	+1 9.2	23 51 10.32	−41 51 17.1	9.3495	0.0241
26	13 7 3	5	8, 8	−0 7.23	−4 56.0	23 50 57.57	−41 49 0.6	9.4052	9.8430
27	7 12 25	6	8, 8	−0 31.34	−1 1.5	23 38 2.39	−39 14 25.6	9.7335n	0.2087n
28	7 53 2	8	8, 8	−0 21.21	+3 23.1	23 22 47.41	−35 41 44.5	9.5266	0.0369n
Oct. 2	7 59 3	10	.., 4	....	+0 28.2	....	−24 13 9.4	....	0.2838n
2	8 11 30	10	6, ..	+2 27.47	....	22 42 15.66	....	9.3773n	....
5	8 19 37	11	9, 8	+0 54.43	+5 59.4	22 24 9.29	−17 36 18.0	9.1768n	0.4292n
6	8 48 56	12	8, 8	−0 11.99	+1 2.3	22 20 47.80	−15 36 48.2	8.8502n	0.4530n
7	7 57 50	14	8, 8	−0 17.33	−2 47.5	22 16 54.14	−13 59 46.1	9.2083n	0.5061n
9	8 2 30	16	8, 8	−0 11.42	+0 38.1	22 10 5.35	−11 2 31.2	9.0790n	0.5532
10	8 37 0	18	8, 8	−0 5.90	−4 50.7	22 7 5.70	−9 45 51.5	8.5066n	0.5696n
11	7 54 9	19	8, 8	+0 24.57	−2 37.1	22 4 43.29	−8 33 5.0	9.0373n	0.5916n
11	8 23 27	20	12, 8	−0 37.08	−2 42.3	22 4 40.02	−8 31 38.5	8.6744n	0.5895n

MEAN PLACES FOR 1914.0 OF COMPARISON STARS

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$0^h\ 38^m\ 27^s.40$	$+5^s.00$	$-49°\ 1'\ 2''.0$	$+26''.1$	Connected with * 2 $\Delta\alpha = -0^m 0^s.91$, $\Delta\delta = -3'34''.4$
2	0 38 28.31	+5.00	−48 57 27.6	+26.1	Argentine General Catalogue 643
3	23 56 42.15	+4.93	−42 21 52.3	+22.4	Argentine General Catalogue 32366
4	23 50 37.55	+4.93	−41 52 48.3	+22.0	Delavan La Plata Meridian Circle 2 obs.
5	23 50 59.88	+4.92	−41 44 26.7	+22.1	Argentine General Catalogue 32270
6	23 38 28.87	+4.86	−39 13 45.1	+21.0	Connected with * 7 $\Delta\alpha = -0^m 0^s.90$, $\Delta\delta = -2'53''.5$
7	23 38 37.87	+4.86	−39 10 51.6	+21.0	Cordoba Zone Catalogue 994
8	23 23 3.87	+4.75	−35 45 27.6	+20.0	Connected with * 9 $\Delta\alpha = -0^m 50^s.11$, $\Delta\delta = -1'43''.5$
9	23 23 53.98	+4.75	−35 43 44.1	+20.0	Argentine General Catalogue 31774
10	22 39 43.83	+4.36	−24 12 58.4	+17.2	Argentine General Catalogue 30961
11	22 23 10.73	+4.13	−17 42 34.3	+16.9	Washington A. G. Catalogue 8381
12	22 20 55.72	+4.07	−15 38 7.6	+17.1	Connected with * 13 $\Delta\alpha = -0^m 5^s.00$, $\Delta\delta = +5'58''.5$
13	22 21 0.72	+4.07	−15 44 6.1	+17.1	Washington A. G. Catalogue 8364
14	22 17 7.46	+4.01	−13 57 16.8	+18.2	Connected with * 15 $\Delta\alpha = -0^m 32^s.52$, $\Delta\delta = -3'54''.5$
15	22 17 39.98	+4.01	−13 53 22.3	+18.2	Washington A. G. Catalogue 8347
16	22 10 12.86	+3.91	−11 3 26.6	+17.3	Connected with * 17 $\Delta\alpha = +2^m 56^s.20$, $\Delta\delta = +3'51''.2$
17	22 7 16.67	+3.90	−11 7 17.5	+17.0	Harvard A. G. Catalogue 7835
18	22 7 7.75	+3.85	−9 41 18.2	+17.4	Harvard A. G. Catalogue 7834
19	22 4 14.91	+3.81	−8 30 45.4	+17.5	Connected with * 20 $\Delta\alpha = -1^m 58^s.38$, $\Delta\delta = -1'31''.7$
20	22 6 13.28	+3.82	−8 29 13.8	+17.6	Vienna Ottakring A. G. Catalogue 7943

OBSERVATION OF COMET MELLISH, 1915 *a*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY BERNHARD H. DAWSON.

1915 ANN ARBOR M. T.		*	COMP.	Δα	Δδ	APP. α	APP. δ	LOG pΔ FOR α	LOG pΔ FOR δ
Feb. 17	$15^h 13^m 45^s$	1	8, 8	$+0^m 31^s.15$	$-9'$ 5″.2	$17^h 12^m 8^s.51$	+2° 37′ 7″.6	9.586n	0.758
17	15 44 7	2	8, 8	+0 16.63	+9 58.3	17 12 10.05	+2 37 0.7	9.551n	0.757
19	14 58 24	4	8, 8	−0 3.56	−7 12.5	17 14 40.09	+2 28 2.7	9.595n	0.771
Mar. 12	13 56 56	6	8, 8	+0 5.70	−7 2.4	17 41 4.25	+0 44 5.8	9.600n	0.768
Apr. 3	13 2 32	7	8, 8	+0 35.13	+4 6.5	18 8 25.93	−2 4 7.1	9.596n	0.777
7	13 16 34	9	8, 8	−0 29.48	−10 28.7	18 13 27.75	−2 50 3.7	9.571n	0.782
8	13 16 49	10	10, 10	+0 8.13	+9 50.8	18 14 43.40	−3 2 34.8	9.568n	0.783
10	13 58 50	11	10, 10	+0 31.30	−9 25.4	18 17 17.84	−3 29 26.9	9.498n	0.789
10	14 32 31	13	—, 3t	....	+7 44.9	....	−3 30 4.6	......	0.792
11	12 38 3	14	8, 8	−0 43.86	−3 51.2	18 18 29.64	−3 43 4.7	9.599n	0.792
11	14 11 31	14	8, 8	−0 38.92	−4 48.0	18 18 34.58	−3 44 1.5	9.468n	0.792
13	13 47 41	15	7t, —	+1 17.32	....	18 21 7.28	....	9.503n	.....
13	14 10 51	16	8, 8	−0 8.80	+1 19.8	18 21 8.57	−4 14 17.1	9.458n	0.795
16	12 31 53	17	8, 8	+0 16.40	+2 17.8	18 24 56.68	−5 3 33.3	9.594n	0.787
16	14 16 12	17	8, 8	+0 21.96	+0 59.3	18 25 2.24	−5 4 51.8	9.428n	0.801
May 10	13 41 22	18	8, 8	−0 1.97	+6 20.1	19 2 10.63	−18 45 53.7	9.389n	0.866
17	14 14 6	19	8, 8	+0 45.30	+0 54.5	19 19 16.41	−27 32 53.2	9.252n	0.905

MEAN PLACES OF COMPARISON STARS.

*	α 1915.0	RED. TO APP. PL.	δ 1915.0	RED. TO APP. PL.	AUTHORITY
1	$17^h 11^m 36^s.80$	$+0^s.56$	+2° 46′ 29″.8	−17″.0	A. G. Albany 5706
2	17 11 52.85	+0.57	+2 27 19.3	−16.9	Connected with * 3
3	17 11 57.28	+0.57	+2 16 51.2	−16.9	A. G. Albany 5708
4	17 14 43.05	+0.60	+2 35 32.2	−17.0	Connected with * 5
5	17 15 20.88	+0.60	+2 38 48.0	−17.0	A. G. Albany 5730
6	17 40 57.44	+1.11	+0 51 25.3	−17.1	A. G. Nicolajew. 4400
7	18 7 49.14	+1.66	−2 7 58.9	−14.7	Connected with * 8
8	18 7 42.64	+1.66	−2 16 43.8	−14.7	A. G. Strassburg 6091
9	18 13 55.48	+1.75	−2 39 20.8	−14.2	A. G. Strassburg 6121
10	18 14 33.48	+1.79	−3 12 11.6	−14.0	A. G. Strassburg 6129
11	18 16 44.71	+1.83	−3 19 47.7	−13.8	Connected with * 12
12	18 16 55.23	+1.83	−3 8 43.9	−13.8	A. G. Strassburg 6139
13	18 19 35.32	+1.83	−3 37 35.9	−13.6	A. G. Strassburg 6159
14	18 19 11.65	+1.85	−3 39 0.0	−13.5	Connected with * 13
15	18 19 48.04	+1.92	−4 8 2.0	−13.2	A. G. Strassburg 6161
16	18 21 15.46	+1.91	−4 15 23.8	−13.1	Connected with * 15
17	18 24 38.28	+2.00	−5 5 38.8	−12.3	A. G. Strassburg 6182
18	19 2 9.84	+2.76	−18 52 9.8	− 4.0	Argentine General Catalogue 26165
19	19 18 27.99	+3.12	−27 33 48.1	+ 0.4	Argelander-Oeltzen 19467

REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY DURING THE YEAR 1912

By WALTER M. MITCHELL

The seismographic equipment of this observatory has been described in a previous number of this publication. The seismographs have been in constant operation during the past year, and have probably recorded all the severe earthquakes wherever occurring, besides numerous minor disturbances and microseisms. The total number of distinct shocks recorded is eighteen; of these, the most severe was that of July 7th.

There have been few changes in the adjustments of the instruments. The periods of the pendulums of the Bosch Tromometers have been adjusted so that now both have the same value, approximately 12 seconds. The Wiechert Vertical Seismograph made a feeble response to our efforts at adjustment, and has yielded two very small records,—this was in the early part of the year. Since then it has relapsed to its former state of inefficiency. The principal fault seems to be one of design; the instrument apparently lacks sensitiveness.

Microseismic disturbances have been less numerous during the year 1912, than during the preceding years. This is particularly true of the short period, or "regular" microseisms. The irregular microseisms of the type shown in Figures 3 and 4, Plate XIII of this volume, have been proportionately more frequent than in the preceding period.

As before noted all types of microseisms are more frequently recorded during the winter months than at any other time of year. The irregular microseisms have been almost invariably recorded during the coldest weather, at the times when the surface of the ground is frozen. During January and February these tremors were almost continuous, and those months were by far the coldest of the year. Similarly during a short period of cold weather in the month of December, these irregular microseisms were conspicuous on the seismograph records. One feature in connection with these tremors has been particularly noted, namely, that the strongest irregular tremors are almost invariably recorded during the early hours of the day; that is during the three or four hours after 8 a. m., at which time the sheets are changed. This seems to indicate that there is some connection between these tremors and the daily rise in the temperature resulting from the appearance of the sun above the horizon. The presence of actual sunshine does not seem to be essential, as is learned from a comparison of the record of microseisms with the meterological record. However, the daily rise in temperature takes place regardless of actual sunshine, so that the absence of this would not necessarily preclude the heating effect as a contributing cause. It seems more likely that the causes of these irregular microseisms will be found in the changes of the temperature of the air, and in the barometric pressure rather than in any change in the actual temperature of the surface of the ground. That the causes are atmospheric is supported by Klotz' investigations of the correlation between microseisms observed at Ottawa and barometric pressures over the neighboring regions. It seems safe to assume that the surface of the ground must be in a proper condition to render changes of atmospheric conditions effective. The frozen condition of the ground is probably a contributing cause, but is apparently not sufficient in itself to produce microseisms of this character, for frequently the seismograph records nothing unusual when the surface of the ground is hard frozen.

The interpretation of these particular types of disturbances recorded by the seismograph is one of great difficulty, as there are probably many factors which modify the appearance of the actual record. The problem is one of great interest, but it is one that can only be solved by cooperation, and by the comparison of records and observations made at many stations. It is hoped that the present type of seismograph will be ma-

terially improved, so that the seismogram will be a record of the actual movement of the earth particle, free from the spurious vibrations and tremors due to the swinging of the pendulum.

The data referring to the several shocks recorded and to the microseisms are given below. The manner of presenting this data, and the notation used, follow the scheme employed in the former paper with the exception that in accordance with the customs of other observatories the times of the phase "K" (end of long waves) have been omitted. All times are given in Central Standard Time, midnight to midnight; to obtain Greenwich civil time add six hours. Remarks follow, which give the nature and the peculiarities of the record of the shock.

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	F	A	Δ
	1912		h m	h m	h m	h m	h m	m.m.	mgm.
77	Jan. 31	B—EW	14 20.0	14 26.2	14 34.3	14 34.6	15 7	18.1	5.0
		B—NS	14 19.9	14 26.1	14 34.3	14 35.0	15 12	12.0	
		W—EW	14 21.1	14 25.9	14 34.0	14 34.9	14 50	5.0	
		W—NS		14 25.3	14 33.9	14 34.3	14 48	4.0	
78	Mar. 11	B—EW		4 35.3	4 39.2	4 40.0	5 17	15.5	
		B—NS			4 38.0	4 40.0	5 16	15.1	
		W—V			4 38.8			0.2	
79	May 6	B—EW	13 9.5	13 14.2	13 24.0	13 26.1	14 7	25.1	4.7
		B—NS	13 9.4	13 14.2	13 25.0	13 27.2	14 7	36.1	
		W—EW		13 14.2	13 23.8	13 24.5	13 5	5.2	
		W—NS	13 9.5	13 14.4	13 24.9	13 25.2	13 4	6.1	
		W—V			13 24.2			0.4	
80	May 22	B—NS	20 46.5	21 12.5	21 29.1	21 35.7	22 18	6.0	
81	June 8	B—EW		0 13.0	0 16.0			1.1	
		B—NS		0 12.8	0 16.8			3.0	
82	June 8	B—EW	1 45.7	1 54.5	2 2.3	2 3.3		37.1	
		B—NS	1 50.7	1 59.8	2 2.3	2 3.7		24.2	
83	June 10	B—EW	10 12.6	10 23.0	10 32.8	10 33.1	11 14	11.1	6.5
		B—NS	10 12.5	10 23.0	10 32.6	10 32.8	11 14	14.9	
		W—EW	10 14.6	10 25.0	10 34.7	10 34.9	11 6	3.1	
		W—NS	10 14.6	10 25.0	10 34.8	10 34.9	11 5	3.2	
84	June 12	B—EW	6 49.5	6 54.3	6 57.1	6 57.4	7 16	4.0	3.1
		B—NS	6 49.3	6 54.1	7 0.1	7 1.1	7 15	4.0	
		W—EW	6 49.7	6 54.3	6 57.3		7 4	2.5	
		W—NS	6 49.5	6 54.3	6 59.8	7 1.2	7 5	1.5	
85	July 7	B—EW	3 5.9	3 12.3	3 20.0		4 15	>72.0	4.4
		B—NS	3 7.3	3 13.8	3 21.0		4 20	>71.0	
86	July 8	B—EW	16 2.7	16 9.0†	16 16.8	16 20.5	16 41	16.2	4.5
		B—NS	16 3.2	16 9.7†	16 17.8	16 20.8	16 46	15.8	
		W—EW	16 2.8	16 8.9†	16 17.6	16 18.0	16 36	19.8	
		W—NS	16 2.7	16 9.2†	16 17.3	16 20.3	16 33	14.8	
87	Aug. 8	B—EW	19 51.8	20 2.1†	20 17.3	20 20.3	20 55	10.0	8.1
		B—NS	19 51.7	20 1.1†	20 10.6	20 18.4	21 6	9.0	
		W—EW	19 51.0	20 2.2	20 17.0	20 17.2	20 55	3.8	
		W—NS	19 51.7	20 2.2	20 12.2	20 17.4	20 56	2.5	
88	Aug. 18	B—EW	15 21.4	15 23.0	15 24.9*	15 25.3	15 29	3.0	1.8
		B—NS		15 21.7	15 24.9*		15 30	1.1	
		W—EW		15 22.3*	15 24.3		15 28	4.0	
		W—NS		15 22.3*	15 24.3		15 24	1.5	
89	Sept. 10	B—EW		10 18.6	10 20.4	10 20.5	10 23	5.3	1.4
		B—NS		10 18.5	10 20.4	10 20.5	10 22	2.0	
		W—EW		10 17.5	10 19.4	10 19.5	10 21	4.4	

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	F	A	Δ
	1912		h m	h m	h m	h m	h m	m.m.	mgn.
90	Sept. 29	B—EW			15 55.0		16 6	0.2	
		B—NS			15 56.9	15 58.3	16 7	0.5	
91	Nov. 7	B—EW	1 48.8*	1 55.5*	1 59.3*		2 52	7.8	3.7
		B—NS	1 48.7*	1 55.5	1 59.2*		2 38	7.5	
		W—EW	1 49.0*	1 55.5*	1 59.2		2 39	3.0	
		W—NS	1 49.0*	1 55.6*	1 59.3		2 38	3.0	
92	Nov. 19	B—EW		8 0.8	8 5.5*		8 29	5.5	
		B—NS		8 0.8	8 5.5*		8 28	8.5	
		W—EW		8 0.6	8 5.3		8 28	3.0	
		W—NS		8 0.6	8 5.3		8 28	4.0	
93	Dec. 7	B—EW			17 6.1*		17 14	2.0	
		B—NS			17 5.8*		17 11	1.8	
		W—EW			17 6.0*		17 13	2.3	
		W—NS			17 6.1*		17 11	1.5	
94	Dec. 9.	B—EW		2 44.6	2 51.0		3 7	5.1	4.4
		B—NS	2 38.2	2 43.6	2 52.4	2 52.6	3 8	26.0	
		W—EW	2 38.2	2 43.9	2 50.3		3 7	2.5	
		W—NS		2 44.3	2 52.3		3 7	4.0	

REMARKS

77. According to newspaper reports this shock occurred in Alaska. Agreement in distance good.

78. Preliminaries are very indistinct. Hence times are uncertain, and no estimate is made of distance. Slight record on Wiechert Vertical. No record on Wiechert Horizontal.

79. Distance is somewhat uncertain as P is not clearly marked. Two main shocks. Second follows first after an interval of three minutes. Recorded on Wiechert Vertical Siesmograph.

80. Preliminaries are very uncertain, hence no attempt is made to determine the distance. Shock consists of four groups of waves or pulses, at intervals of about 2.5 minutes. Time signals are defective on B-EW and both Wiechert records, hence these cannot be read.

81. Continuous tremors and small shocks during the previous day. See in record of microseisms.

82. This shock while quite severe is very unsatisfactory, as it is quite impossible to differentiate the phases owing to continuous tremors. The hour signals on the Wiechert record are nearly all missing. Consequently no times can be given for this instrument. B-EW time signals are very faint and uncertain. Another smaller shock followed at about 7 hrs, but all time signals are missing.

83. Distance probably not accurate.

84. Times a little uncertain owing to incomplete clock signals. Record in both instruments is so similar that it is conspicuous. Distance fairly accurate.

85. A severe shock. Recording pen swung off sheets from 3 hrs 25 min to 3 hrs 28 min. Wiechert Horizontal out of order, hence no record. Distance fairly accurate.

86. Preliminaries are not well marked, but distance seems to be accurate. Times may not be accurate as signal clock was moved to a new location during this day.

87. Distance is probably not accurate.

88. A very small disturbance, probably not far distant. Times are somewhat uncertain owing to irregularity of signal clock.

89. A very small disturbance, mainly in the EW component. Not recorded on W-NS.

90. This disturbance consists of sine curves of small amplitude. No preliminaries are visible. Only faint traces of this shock on the Wiechert record.

91. Preliminaries are well marked. Main waves consist of irregular tremors without the characteristic maximum. A second impulse fol-

lows at 2 hrs 5.5 min. Direction of movement SE-NW. Distance not accurate.

92. P is not distinguishable. A single sharp impulse at L, followed by irregular tremors of small (2-3mm) amplitude.

93. No preliminaries visible. Small irregular tremors frequent all during the day. Shock commences with a single impulse, direction NE-SW. End of tails lost in microseisms.

94. A decided shock. Movement almost entirely NS. Distance accurate.

MICROSEISMS.

1912.

Jan. 1-2.

Slight irregular tremors during the day. These show most prominently on B — E W record.

Jan. 2-3.

The same tremors are continued.

Jan. 3-4.

Strong irregular tremors on both Bosch records. Stronger in E W component until Jan. 4. 0 hrs. when the N S component becomes stronger. No traces of these tremors on the Weichert records.

Jan. 4-5.

Strong irregular tremors continued. These die out in E W component by Jan. 4, 18 hrs., but continue with only slightly diminished intensity in the N S. No traces on the Weichert record.

Jan. 5-6.

Moderately strong irregular tremors on both Bosch records. Scattered groups of short period microseisms on the N S record. No traces on Weichert record.

Jan. 6-7.

Strong irregular tremors on Bosch records during the early part of this period.

Jan. 7-8.

Tremors continued.

Jan. 8-9.

Tremors continued. But on B — E W these are much diminished after Jan. 8, 17 hrs. Nothing on Weichert records.

Jan. 9-10.

Occasional tremors during the day, but intensity is much diminished.

Jan. 12-13.

Irregular tremors. Stronger in early part of this period on E W record.

Jan. 13-14.

Moderately strong irregular tremors on B — E W, but not on B — N S. Weichert shows nothing.

Jan. 14-17.

Tremors continued. N S component increasing in strength.

Jan. 17-18.

Intensity of tremors much reduced.

Jan. 19-20.

Occasional irregular tremors of small intensity.

Jan. 20-22.

Tremors continue, gradually increasing in strength.

Jan. 29-30.

Occasional irregular tremors with short period microseisms, the latter are stronger on N S record. Faint traces on Weichert.

Feb. 1-4.

Irregular tremors during this period. These become very strong on Feb. 4.

Feb. 4-5.

Irregular tremors continue, but with diminishing intensity.

Feb. 5-8.

Continuous irregular tremors of small intensity.

Feb. 8-9.

Intensity of tremors diminishing. There have been no traces of these on the Weichert records.

Feb. 12-14.

Continuous irregular tremors, intensity diminishing towards the end of this period. Tremors are more conspicuous on E W record. No traces on Weichert.

Feb. 21-24.

Continuous irregular tremors of small intensity during this period. More conspicuous on E W record. Faint traces on Weichert.

Aug. 22-23.

Scattered groups of regular microseims on B — E W record. Traces of these on W — E W.

Sept. 16-17.

Regular microseisms of small amplitude on B — E W record.

Sept. 29-30.

Slight traces of irregular tremors on both Bosch records.

Nov. 3-4.

Faint traces of regular microseisms with very small amplitude. These show on the Weichert records.

Nov. 7.

A series of regular tremors beginning at 10 hrs. 55 min. continuing for 9 min. These commence again at 11 hrs. 42 min. and continue for 10 min. This was probably a small shock, but phases cannot be distinguished. Amplitude less than 0.5 mm. These tremors are most conspicuous on B — E W, only very slight traces on Weichert record.

Nov. 13-14.

Irregular tremors of small amplitude on B — N S.

Nov. 14-15.

Irregular tremors continue on B — N S. Supporting pier shifts during day, indicated by decided "drift" of recording pen.

Nov. 16-19.

Irregular tremors on B — N S continue.

Nov. 21-22.

Slight tremors on B — E W, these appear also on B — N S, with traces on Wiechert records.

Nov. 23-24.

Slight irregular tremors on B — N S.

Nov. 28-29.

Tremors begin at the end of this period. These are generally irregular and quite prominent on B — N S. Conspicuous on Wiechert records.

Nov. 29-30.

Tremors continue through this period, diminishing in intensity at the end.

Dec. 2-3.

Faint traces of irregular tremors on B — N S.

Dec. 6-7.

Strong irregular tremors during the early portion of this period, gradually diminishing in intensity. Conspicuous on B — N S, but not recorded on B — E W. Not recorded on Wiechert instruments

Dec. 7-8.

Small irregular microseisms. These are more conspicuous on B — E W than on B — N S. The Wiechert records also show distinct tremors.

Dec. 9-12.

Conspicuous irregular microseisms on B — N S. These show slightly on B — E W. Intensity diminishes during latter portion of period.

Dec. 12-13.

Very strong irregular tremors on the morning of the 12th. These are strong on the B — N S record, with only traces on the B — E W. Wiechert records do not show these tremors.

Dec. 13-14.

Tremors continue, but with greatly diminished intensity.

Dec. 22-23.

Slight irregular tremors on B — N S.

Dec. 25-26.

Short period regular microseisms. These are equally prominent on both Bosch records. Traces on W — E W. Line traced by pen of Wiechert Vertical is very uneven in intensity, but no tremors.

Dec. 28-30.

Scattered short period regular microseisms on both Bosch records.

Dec 31-Jan. 1.

Scattered regular microseisms continue. Traces on Wiechert records.

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY DURING THE YEAR 1913

By PAUL W. MERRILL

The equipment of this seismological station has been described in the reports for preceding periods. The disposition and constants of the instruments have not been altered.

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1913		h m	h m	h m	h m	h m	mm.	1000 km.
95	Jan. 15	B—EW				6		small	
		B—NS				13 7		small	
96	Mar. 4	B—EW			6 38.1			0.3	
		B—NS		remark	37.8			0.2	
97	Mar. 8	B—EW	9 58.5	10 3.7	10 7.1	10 9.4	>10 30	3.0	
		B—NS	59.0	3.4	6.7	7.5		0.4	3
		W—EW			7.0	8.2		0.9	
98	Mar. 14	B—EW	3 5.4	3 23.1	3 42.4?	3 44.3	4 16	0.7	
		B—NS	4.	17.0	42.1	42.8	15	0.7	13
		W—EW	4.	23.0	42.1	44.1	31	0.9	
		W—NS	4.4	23.1	42.2	44.0	42	0.6	
99	Mar. 30	B—EW	21 51.6*		22 14.9	22 18.7	>22 50	0.7	
		B—NS	51.4*		18.5	19.0	> 50	1.2	8
		W—EW	51.5*		14.0	18.4	>23 0	0.7	
		W—NS	51.5*		13.9	18.0	> 0	0.8	
100	May 16	B—EW				6 17.5		0.2	
		B—NS				17.5		0.2	
101	May 30	B—EW				6 55	> 7 8	1.2	
		B—NS				54	> 9	0.5	
102	June 14	B—EW	2 43.2			3 4.1		0.3	
		B—NS	42.7			3.4		0.2	
103	June 25	B—EW	23 16.0	23 30.7†	23 46.2*	23 55.9	1 30	1.9	
		B—NS		30.8		56.7	0 39	0.5	11
		W—EW				56			
104	July 8	B—EW		18 22.8	18 25.8	18 26.0	18 32	2.5	
		B—NS		22.3	25.2	25.4	35	0.9	
		W—EW		22.8	25.7	26.0	32	0.4	2
		W—NS			25.5	25.8	26	0.1	
105	July 25	B—EW		6 50.4	6 53.6	6 55.2	7 10	1.5	
		B—NS		50.1	54.4	56.7	9	0.7	2 +
106	Aug. 6	B—EW	16 27.1	16 32.2	16 38.6	16 44.2	17 48	9.8	
		B—NS	23.9	31.8	41.0	48.3	45	12.0	
		W—EW		33.8		44.0	16 58	1.0	5
		W—NS		31.1	41.2	48.2	17 1	1.1	
		W—V				50.2		1.	
107	Oct. 1	B—EW		22 35.2	22 38.9	22 42.6	23 4.9	4.1	
		B—NS	22 29.4	34.7	40.6	45.3	3.4	1.5	3½
108	Oct. 4	B—EW		16 15.6		16 21.9		0.2	
		B—NS	16 11.8			27.0		0.15	
109	Oct. 10	B—EW				23 10		0.3	
		B—NS				8		0.15	

* = well defined. † = gradual.

REMARKS.

Measurements not conveniently included in the scheme of the table are given below. Some slight shocks are described under the head of microseisms.

The three values of the distance computed by the Laska formulae,

$$(1)\quad \Delta = S - P - I.$$
$$(2)\quad \Delta = 1/3\,(L - P).$$
$$(3)\quad \Delta = 1/2\,(L - S + I).$$

nearly always decrease from (1) to (3). The mean, which usually differs but little from (2), is apparently not far from the truth.

95. A weak shock extending over many minutes. Small motion shown on Wiechert. Slow microseisms during the day.

96. A slight shock of small irregular waves. B-E W strongest portion from 6 h 38.1 m to 42.5 m, with a lull from 40.2 m to 41.6 m. B-N S from 6 h 37.8 m to 41.4 m, with a lull from 38.8 m to 40.9 m. Nothing definite on W.

97. Tremors died out very gradually. W-N S record imperfect but recorded motion is of very small amplitude. On B-N S there is a stronger group of sinusoidal waves in the tail from 10 h 26.4 m to 29.4 m.

98. It is possible that S and L have been misidentified.

100. B-E W small waves beginning about 6 h 9 m coming to a maximum at 17.5 m, dying away again in a few minutes. B-N S same. Also shown on W-N S.

101. B-E W small waves beginning 6 h 34 m, gradually increasing. B-N S tremors begin gradually about 6 h 32 m. W-E W waves of maximum amplitude 0.2 mm from 6 h 53 m to 57 m. W-N S trace? W-V slight tremors (amplitude scarcely 0.1 mm) from 6 h 53.8 m to 57.3 m.

102. B-E W undulations last for half an hour after M, starting up again 70 m after M. B-N S undulations cease about 10 m after M but start up again about 70 m after M.

103. The stronger waves show for 2 or 3 m on W-E W. The slightest irregular trace on W-N S.

106. W-V record poor. Long waves began at 16 h 47.8 m and ended at 53.4 m.

107. The Panama earthquake.

108. A small record. No well marked phases.

109. A weak disturbance having a gradual increase and decrease in intensity.

MICROSEISMS.

The characteristic features of the microseismic disturbances recorded here have been described and discussed in previous reports.

The microseisms recorded as "groups of sinusoidal waves" may in some cases be due to the passage of trains on tracks one-half kilometer north. There is some evidence, however, that these are real seismic tremors which are assisted in recording themselves by the rapid vibrations given the pen by trains. In this connection see *Hobbs' Earthquakes*, p. 264. It appears that train effects are not the same, or even of the same general character, at all times.

MICROSEISMS 1913.

1913.

Jan. 1-7.
Irregular sinusoidal waves on the B instruments. Traces on W. On Jan. 3-4 stronger EW than NS.

Jan. 7-9.
Small irregular motions but nearly continuous.

Jan. 8-13.
Regular sinusoidal waves of small amplitude, increasing to a maximum on 9-10, and then dying away very slowly.

Jan. 13-14.
As above but more active.

Jan. 14-15.
Traces.

Jan. 20-23.
Weak sinusoidal tremors.

Jan. 28-29.
Small groups of sinusoidal tremors on B and W.

Jan. 29-30.
Same but weaker.

Jan. 31-Feb. 1.
Tremors, more or less continuous shown by B—NS.

Feb. 1-10.

B—EW groups of sinusoidal waves. B—NS nearly continuous tremors. Motions of very small amplitude recorded on W.

Feb. 3-4.

B—NS shows groups of sinusoidal tremors with very small waves connecting the groups.

Feb. 5-8.

Stronger. B—NS shows continuous motion.

Feb. 8-9.

Feebler.

Feb. 9-10.

Somewhat stronger.

Feb. 13-14.

Tremors throughout day, best recorded by B—NS as during all this period.

Feb. 14-15.

Groups of tremors showing more plainly on NS records.

Feb. 22-23.

Groups of sinusoidal tremors. Motion nearly continuous on B—NS.

Feb. 23-24.

Continuous motion by B—NS.

Feb. 24-25.

Traces nearly all day B—NS.

The amplitudes of the tremors during January and February have been small, scarcely exceeding one or two tenths of a millimeter.

March 1-2.

B—EW a few slight tremors in latter part of day B—NS strong irregular tremors during the last few hours. Effects are seen on W records.

March 2-3.

B—NS small tremors all day with groups of stronger irregular waves.

March 5-6.

B—NS lines slightly wavy all day.

March 6-7.

Same. Slight irregularities shown by B—EW.

March 7-8.

Very slight slow motion indicated by B—EW with a few groups of sinusoidal waves of about 0.1 mm amplitude.

March 9-10.

B—NS small undulations in morning, gradually dying away.

March 15-18.

Slight tremors.

March 21-22.

B—NS microseisms beginning between 8 and 9 o'clock, quite strong for 5 or 6 hours, continue all day with diminished intensty; amplitude 0.5 mm, occasionally 0.7 mm. B—EW shows waves of 0.2 or 0.3 mm amplitude during strongest period on NS. Some evidences of action on W.

March 28-29.

B—EW small sinusoidal waves throughout most of day. Trains seem to assist pen to record.

March 29-30.

B—NS slight disturbances throughout the day.

March 31-April 1.

B—NS feeble tremors particularly in first half of day.

April 1-2.

Feeble sinusoidal microseisms on B—NS.

April 4-7.

B—NS lines slightly wavy. Traces on W?

April 30.

B—EW irregular waving of the pen from about 6h 0m to 30m; amplitude 0.1 mm ±. B—NS same, with even smaller amplitude.

May 9-11.

Very small sinusoidal waves.

May 17-18.

B—EW groups of sinusoidal waves throughout the day—trains? B—NS same but weaker.

May 18-19.

Small waves and irregularities throughout the day on B instruments.

May 19-20.

Same, very slight.

June 8-17.

Throughout this period there are numerous well-marked groups of sinusoidal waves of period 5 s ±, extending over a minute or so. These may be due to trains.

July 12.

B—NS a few irregular microseisms from 9h to about 20h.

July 28.

B—NS slow microseisms or a feeble indefinite shock at 0h 15m. Shown on B—EW with strongest motion at 0h 11m.

Sept. 3.

Microseismic shock from 15h 51m to 16h 12m on B—EW; from 15h 44m to 16h 17m on B—NS.

Sept. 4-7.

B—EW irregular microseisms. Less conspicuously present on B—NS.

Sept. 14-15.

Microseisms of very small amplitude on B instruments.

Sept. 20-23.

Slow microseisms of very small amplitude on B—NS, with traces on B—EW.

Sept. 30-Oct. 1.

Some feeble irregular microseisms on B instruments.

Oct. 1-5.

W—EW shows occasional irregular disturbances.

Oct. 6-10.

B—EW a few weak microseisms.

Oct. 10-11.

B—NS shows weak disturbances similar to above.

Oct. 11-15.

Small microseisms on B instruments.

Oct. 14.

B—NS a maximum of slow waves of period ½ m about 3h om. The waves are seen on B—EW but maximum is 8 or 10m later.

Oct. 15-16.

Weak microseisms of short period.

Oct. 16-17.

Trains seem to have an unusually strong effect. This has been noticed on other occasions.

Oct. 16.

B—NS shows slow irregular movements beginning about 15h and lasting for several hours. Less extensively recorded on B—EW.

Oct. 17-18.

B—NS lines irregularly wavy in small amplitude all day. A little of the same seen on B—EW.

Oct. 18-19.

The above dies away.

Oct. 22-23.

Sinusoidal microseisms of period 4 or 5 s and amplitude 0.1 mm are shown on B instruments, being better marked on B—EW.

Oct. 23-24.

B—EW above shown: there are larger waves (period 20 s) of amplitude 0.2 mm beginning about 8h 18m on Oct. 23, lasting for 5 or 6 m. Traces of same on B—NS.

Nov. 1-3.

B—NS and weaker on B—EW small rather irregular disturbances throughout day, which continue with about the same characteristics until Nov. 13.

Nov. 10.

Groups of waves shown as follows:

INST.	TIME	PERIOD	AMPLITUDE
	h m m	s	mm.
B—EW	16 9 to 14		
	16 to 20	20	0.2
	20 to 27		
B—NS	18	20–25	0.15
W—EW	9 to 14 15 to 27	23	0.1

Only slightest trace on W—NS.

Nov. 21-22.

B instruments sinusoidal waves of short period and small amplitude, being stronger early in the day.

Nov 22-23.

Weaker.

Nov. 23-24.

Stronger.

Nov. 24-27.

Same.

Nov. 27-28.

Fainter. Motion of trains exaggerated on B—EW showing waves 12s long.

Dec. 3-6.

Slight microseisms, being very weak on 4-5.

Dec. 5.

B—EW regular sinusoidal waves all day. Well marked group of waves of amplitude 0.3 mm beginning at 18h 29.5 m and stopping abruptly at 31.0 m.; Period of waves, 4s. B—NS irregular sinusoidal waves of 0.2 mm amplitude begin at 18h 26.4m, continuing to 30.2m after which they gradually die out. W—EW regular sinusoidal waves from 18h 29.7m to 31.1m; amplitude 0.3 mm, period 4+s; beginning of disturbance at 18h 21.7m?

Dec. 6-12.

B instruments and W—EW show sinusoidal disturbances which are stronger on 8-9.

Dec. 12-15.

Small irregular waves on B—EW which are stronger on 12-13.

Dec. 15-27.

Sinusoidal microseisms throughout this period B—EW, B—NS, W—EW. Strongest 20-21.

Dec. 27-28.

B—NS numerous groups of regular sinusoidal waves, amplitude 0.1 to 0.4 mm, period 6s, with fainter waves connecting the groups. B—EW record imperfect but similar waves shown. W—EW similar waves, amplitude 0.2 mm, period 5s.

Dec. 28-29.

B—EW many sinusoidal waves particularly in early part of day, amplitude 0.3 mm, period 5-6s. B—NS same but weaker. Waves of smaller amplitude shown on W instruments.

ERRATA

Page 14, Column 1, Line 8: For 20″.565, Read 20″.656.

Other determinations are available as follows:

Urie	20″.699
Lindsay	20″.707
Dawson	20″.634

Page 34, Last line: For May 1900, Read May 1912.

Page 41, Plate VIII: For Cillimator, Read Collimator.

Page 42, Second line of table: For 5,700 and 0.79Å, Read 4,000 and 1.12Å respectively.

NOTE ON SPECTROGRAPH DESIGN.

On page 37 of this volume, column 2, lines 39 to 42, Mr. W. H. Wright is mentioned by the author as the designer of the "Southern Mills Spectrograph"; and on page 43, column 2, lines 20 to 24, he is named as the inventor of the *type* of instrument adapted to single-prism construction at the Allegheny Observatory. These allusions to the development of the stellar spectrograph do not take into account the important work of Director W. W. Campbell of the Lick Observatory, from whose writings it is my pleasure to make the following quotations, by which any reference of mine in this connection should be superseded.

"A three-prism spectrograph, constructed in our instrument shop from my drawings, embodied the results of many conferences between Mr. Wright and myself." From *Publications of the Lick Observatory,* Vol. IX, page 6; under title, "Organization and History of the D. O. Mills Expedition to the Southern Hemisphere."

"My assistant and colleague, Wright, suggested that such an instrument should be supported *near its two ends,* like a bridge truss or beam, in order to give minimum flexure. Acting upon this suggestion I designed the supports of the spectrograph of the D. O. Mills Expedition to Chile, in 1901, as shown in the illustration....." From *Stellar Motions,* Chapter II, page 47.

R. H. Curtiss.

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END OF VOLUME I.

PUBLICATIONS

OF THE

ASTRONOMICAL OBSERVATORY

OF THE

UNIVERSITY OF MICHIGAN

COMPOSED AND PRINTED BY
THE ANN ARBOR PRESS
ANN ARBOR, MICHIGAN

Plate A. The Observatory of the University of Michigan, 1916

DETROIT OBSERVATORY

PUBLICATIONS

OF THE

ASTRONOMICAL OBSERVATORY

OF THE

UNIVERSITY OF MICHIGAN

Volume II.

ANN ARBOR:
PUBLISHED BY THE UNIVERSITY
1916

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PREFACE

In planning the reorganization of this Observatory in 1905, one of the objects sought was to provide means for modern astrophysical investigations. To this end a large reflecting telescope of the Cassegrain form, having an aperture of 37½ inches and an equivalent focal length of sixty feet, was designed and constructed at the Observatory under my supervision, the optical parts having been obtained from the John A. Brashear Company of Pittsburgh. This instrument was completed in May, 1911, and since then it has been used almost exclusively for photographing stellar spectra with a single-prism spectrograph. The telescope, spectrograph, and engines for measuring spectra have been briefly described in the first volume of these *Publications,* which also contains some of the first results secured by the aid of this telescope. More than thirty-seven hundred spectrograms have now been made, and with few exceptions they are suitable for exact measurement. Nearly all of the papers of the present volume are based upon data obtained from a small proportion of these spectrograms, that is, from those which have already been measured and discussed. Other investigations are in progress.

The spectrographic work has been under the immediate supervision of Professor Ralph H. Curtiss, who designed the spectrograph and measuring engines, and, with Dr. Merrill, planned the programs for work. Dr. Curtiss has also prepared the enlarged spectra, which are used as illustrations in this volume.

William J. Hussey.

Ann Arbor, November, 1916.

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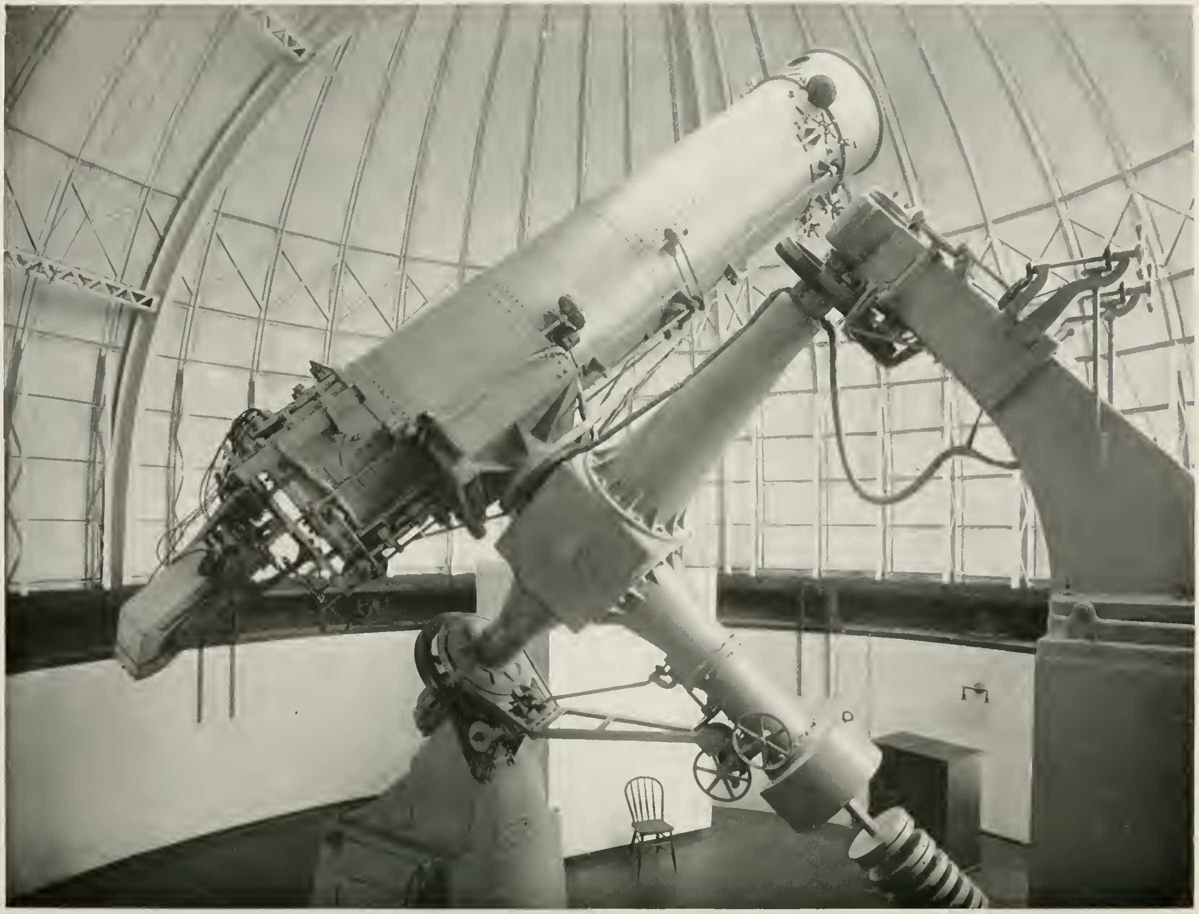

Plate B. The Thirty-seven and One-half Inch Reflecting Telescope

STUDIES OF CLASS B STELLAR SPECTRA CONTAINING EMISSION LINES

THE SPECTRUM OF γ CASSIOPEIAE

By RALPH H. CURTISS

INTRODUCTION.

Immediately after the 37½-Inch Reflector of this Observatory was completed in May, 1911, a program of observation of bright line stellar spectra of Class B was begun with a single-prism spectrograph attached to this telescope. This program was in continuation of a study of spectra of this particular group, inaugurated by the writer in 1906, in connection with a detailed investigation of the spectrum of β Lyræ. At the present time several hundred plates have been made on this program, including short lists of plates on a number of stars and long series on several typical objects.

The apparatus used in connection with this program has been described fully in earlier papers in this Publication.[1] It is interesting to note here that the dispersion of the spectrograph employed in this work is only a little greater than that of the Mellon Spectrograph with which the study of β Lyræ, mentioned above, was carried on. The spectra made with the two instruments are thus readily comparable.

The historical importance of the problem of γ Cassiopeiæ, as well as the relative brightness of the total light of this star, suggested the advisability of a detailed study of its spectrum. The choice of this spectrum for early investigation followed logically in view of the relatively simple character of its observed features. It was hoped that the analysis of this simpler spectrum would assist in the study of more complicated cases whose complex spectral features, sometimes associated with remarkable light variations, have made the problem of these stars a classic one.

GENERAL DATA.

The star, γ Cassiopeiæ (H. R. P. No. 264, α 1900.0 = 0 hr. 50.7 min., δ 1900.0 = $+60^\circ$ 11′) is assigned a visual magnitude of 2.25, without certain evidence of light variation. The integrated light impresses the eye as pure white. This star lies in the Milky Way; it has no measurable parallax; it was found by Boss in his *General Catalogue of 6188 Stars* to have a proper motion of $+0^s.0040$ in right ascension and of $-0''.002$ in declination. Apparently then this star is very distant; and its volume and absolute magnitude must be relatively great.

[1] *Detroit Observatory Publications,* Vol. I, page 37.

THE SPECTRUM.

Classification. The spectra of the stars of the sub-group to which γ Cassiopeiæ belongs are assigned almost exclusively to "Class B and Class A peculiar," or to Class B and Class A with bright lines. The distinguishing characteristic of this sub-group seems to be the presence in the spectra of one or more hydrogen lines of the Huggins series in which emission is strong enough to be observed. The other lines in the spectrum may be bright, dark, or neutral, but the Orion lines outside of the Huggins series of hydrogen are nearly always dark.

Within this sub-group there are variations similar to those existing within the normal Class B and Class A divisions. The relative strength of critical lines of Class B spectra, such as λ 4686, the ζ Puppis series of hydrogen, and the silicon and nitrogen lines near Hδ, indicates affiliation with Class Bo in some cases, while the weakness or absence of these lines with the relative strengthening of the lines of the metals indicates development into Class A in other cases. Indeed emission lines of the type characteristic of these spectra are observed in two Class F spectra and perhaps in Class G.

A knowledge of the distribution of the known bright line spectra of this sub-group among the various divisions of the Draper classification may

be gained by a count of the stars in Table IV, page 182, Volume 56, of the *Harvard Annals* and of eight additional stars in a table by Merrill.[2] Such a count leads to the following results:

TABLE I. DISTRIBUTION OF SPECTRA OF CLASSES B TO F CONTAINING BRIGHT LINES.

CLASS	NUMBER OF STARS
B to B2	19
B3 to B5	43
B6 to B8	6
B9 to Ao	29
A1 to A4	1
A5 to A7	1
A8 to Fo	2

Evidently these stars, so far as present discoveries go, tend strongly to group within the B division of the Draper classification and are rarely found outside of the interval, B to Ao. Possibly the preponderance of Class B spectra among discoveries in this sub-group finds explanation in the fact brought out in the next paragraph.

It is evident also that the total light of these stars, so far as known, is stronger on the average the more nearly their spectra conform to that of Class Bo. Thus, the average B.D. magnitude of fifty-six of these stars in the Harvard table, of spectral classes, Bo to B5, is 5.3, whereas this average magnitude for the twenty-eight stars of Classes B8 to A2 is 8.1.

Though the presence of emission lines is distinctive of this sub-group, the *strength* of the emission lines relatively to the continuous spectrum seems not to be clearly dependent upon the so-called effective age of the star. Doctor P. W. Merrill's study[2] of many of the spectra in this sub-group in Class B throws light on this point. Thus, in his γ Cassiopeiæ and ϕ Persei groups of seventeen stars, in which the hydrogen emission lines are strongest, the average spectrum is rated at Harvard as B3.1, whereas in his b^2 Cygni and Electra groups of twenty-one stars, in which this emission is weaker, the average spectrum has essentially the same rating, or B3.3. This point may be brought out in a more striking manner if we assign intensity 3 to the hydrogen lines in the γ Cassiopeiæ and ϕ Persei groups, intensity 2 to these lines in the b^2 Cygni group, and intensity 1 in the Electra group, determining on this basis the average strength of the hydrogen emission lines for spectra in the *subdivisions* of Class B. The results obtained in this way for thirty-eight stars are given in Table Ia. They do not bear evidence of a connection between strength of hydrogen emission and spectral class within the B division.

TABLE Ia. VARIATION IN INTENSITY AND NUMBER OF HYDROGEN EMISSION LINES WITH SPECTRAL CLASS.

CLASS	INTENSITY OF HYDROGEN EMISSION	NO. OF HYDROGEN EMISSION LINES	NUMBER OF STARS
Bo to B1	2.7	3.4	8
B2	2.2	2.9	11
B3	2.6	2.9	29
B4 to B5	2.0	2.6	14
B8	2.5	2.3	6
Ao	—	3.2	29
A2 to F	—	2.2	4

It is interesting also to consider whether there is any connection between spectral class and the number of hydrogen emission lines visible in stellar spectra of this sub-group, especially in view of the fact that in general the total strength of these emission lines is found to increase with their number. Referring to the 101 stars of Table I, we find for those having hydrogen emission lines from $H\alpha$ to $H\epsilon$ and $H\zeta$, an average spectral class of B3.0; for those to $H\delta$, B7.4; for those to $H\gamma$, B5.0; for those to $H\beta$, B5.9; and for one with $H\alpha$ only, B5. Or, again, if it be permitted to take averages to tenths of numbers of emission lines, the data in column three of Table Ia may be obtained for the 101 stars of Table I, showing the average number of hydrogen emission lines found in the spectra of these stars within subdivisions of Classes B to F. The data for these averages are taken from Table IV, page 182, Volume 56, *Harvard Annals*, with ad-

[2] *Lick Observatory Bulletins*, Vol. VII, page 162.

ditions based on recent results. So far as these data go, there appears to be little or no connection between *intensity or number of hydrogen emission lines* and *average spectral class;* nothing to indicate from this point of view that this sub-group of spectra terminates in reality with Class F. Indeed, on the basis of the facts so far known, the conclusion is suggested that the extension of spectral surveys to fainter objects may result in the discovery of many new members of this sub-group with spectra of Classes A and F and possibly of Class G.

The metallic lines in these spectra, if present, may be bright or dark, both types occurring in some cases in the same spectrum. Sherman[3] and Merrill[2] have pointed out that the metallic bright lines correspond to strong chromospheric emission in a number of cases, and Baxandall[23] called attention to the dominance of iron emission in them.

It is of interest to inquire whether the occurrence of these chromospheric lines is in any way associated with spectral class. In this connection we find that the mean Harvard classification of eleven spectra in which Merrill has found these bright metallic lines is B2.5, only one having a spectrum later than B3, whereas the mean classification of thirty-eight of these spectra examined by Merrill (six not classified by Merrill are excluded) is B3.2. That the spectra of these eleven stars average nearer to Class B0 than does the mean spectrum of Merrill's list, and that ten of these stars have spectra classed as B3 or earlier on the basis of the Orion lines, indicate that the metallic emission lines tend to appear in these spectra only under conditions thought to characterize stars in the earlier stages of development. Apparently, also, when these lines occur, they tend to be stronger when the hydrogen emission is stronger.

Characteristics Historically Considered. Secchi, at the very beginning of his work on stellar spectra, noticed emission lines in the light of γ Cassiopeiæ. In the *Astronomische Nachrichten* No. 1612, under date of 1866, August 23, he states that the spectrum of this star has a bright line at $H\beta$, and several others too faint to measure. In a report published February 8, 1867, Huggins announces his identification of $H\alpha$, as well as $H\beta$, as a bright line and also his observation of some dark lines of absorption in this spectrum.[5] Later both Secchi and Huggins saw D_3 emission in γ Cassiopeiæ in addition to that of $H\beta$ and $H\alpha$.[4]

Vogel, on June 18, 1872, observed $H\beta$ and D_3 as emission lines and saw also an absorption band in the red, but, though he examined carefully the red end of the spectrum, the $H\alpha$ line was not visible.[6]

Von Konkoly examined the spectra of γ Cassiopeiæ and β Lyræ repeatedly, between 1874 and 1883, without seeing bright lines, and in 1882, von Kovesligethy was equally unsuccessful; von Gothard observed both of these stars frequently after the autumn of 1881, but saw no trace of bright lines until a night quite unfavorable for observing in 1883, when, according to his record, on August 13 of that year, he saw bright $H\alpha$ and the absorption band at λ 633$\mu\mu$ in the spectrum of γ Cassiopeiæ.[7]

During this same period (from 1874 to 1883) Copeland records a bright line well seen at about the place of $H\beta$ in this spectrum and another emission line at about λ 477 $\mu\mu$, on October 28, 1877, when there is no record of an examination of the $H\alpha$ region; and, on December 20, 1879, Lord Crawford, J. G. Lohse and Copeland saw $H\alpha$ "superbly visible" with a spectroscope separating the D lines.[8]

The Greenwich record of observations of the $H\beta$ emission line during this period, made with a half-prism spectroscope attached to the 12.8-Inch Refractor, is as follows: 1880, October 1. Brilliant against background of continuous spectrum. Broad and diffuse at edges. Central condensation. November 21. Bright. 1881, December 7. Difficult to measure. Absence of mention of emission lines, D_3 and $H\alpha$, does not imply their extinction, for these observations were made on the $H\beta$ line for the measurement

[3] *American Journal of Science*, Vol. 30, Dec., 1885. *Astronomische Nachrichten*, Vol. 113, page 311.

[4] *Sugli Spettri Prismatici delle Stelle Fisse*, Mem. I, page 10; Mem. II, page 62.

[5] *Monthly Notices*, Vol. 27, page 131.

[6] *Bothkamp Beobactungen*, Heft II, page 29.

[7] *Astronomische Nachrichten*, Vol. 106, page 293.

[8] *Monthly Notices*, Vol. 47, page 92.

of radial velocity and D_3 and Hα were not looked for.[9]

On August 20, 1883, one week after his discovery of the possible revival of intensity of Hα in γ Cassiopeiæ, von Gothard renewed his observations, notwithstanding unfavorable atmospheric conditions, and, with a small slit spectroscope with half prism of low dispersion, obtained approximate wave-lengths and intensities of the bright lines, Hα, D_3, and Hβ, and of the dark band at λ 633 $\mu\mu$. Hα had the greatest intensity and appeared, with a small ocular spectroscope by Zöllner, as a sharp brilliant line. Hβ was more difficult to see and D_3 could be observed only a few times when the seeing was especially good. The relative intensities of Hα, D_3, and Hβ were expressed by the numbers, 5, 1, and 2 respectively. There was no question as to the reality of the observed phenomena on this date, but von Gothard seemed to have had misgivings as to the reliability of his observations of bright Hα on August 13, for in a letter received by von Konkoly, on August 22, he qualified his announcement of the discovery by stating that, on account of the unfavorable atmospheric conditions, the line might have been merely a subjective phenomenon, caused by contrast with a dark band more refrangible than Hα.

On the evening of the receipt of von Gothard's announcement, von Konkoly observed the star at O'Gyalla, first with the dispersion of a train of three prisms of the Zöllner eye-piece spectroscope with a cylindrical lens in the optical train. The Hα line appeared *very faint*. But, when two trains of prisms were used, without the cylindrical lens, Hα was seen as an *exceedingly bright* knot in the narrower thread of continuous spectrum and a much fainter Hβ was noticed. On the same evening, with a little slit spectroscope equipped with one 60° prism, Hα was observed again and compared with the Geissler tube spectrum of hydrogen, but Hβ was too faint to be seen under these circumstances. A strong absorption band was seen to border Hα sharply on its more refrangible side, and, on the less refrangible side, another broad absorption line was suspected.[10]

On August 24, 25 and 26, at the Astrophysical Observatory in Hereny, von Gothard, von Konkoly, and von Than saw Hα and Hβ very well and D_3 less easily, with a Zöllner eye-piece spectroscope of relatively high dispersion attached to the 10¼-inch Browning reflector. Von Konkoly, in his own account of the observations of the twenty-sixth, when the air was very clear and steady, states that the red line was exceedingly bright; D_3 and Hβ emission were well defined; and bright Hγ was seen. The dark absorption band more refrangible than Hα was very distinctly defined and assurance was felt that the line somewhat less refrangible than Hα was not an effect of contrast.[10]

On the following night, August 27, von Konkoly availed himself of the superior power of the 27-Inch Refractor at Vienna, using his own Zöllner eye-piece spectroscope with two trains of three prisms each, without a cylindrical lens. Hα appeared as a knot of light of dazzling brilliance; D_3, Hβ and Hγ were fainter. The broad absorption band, a little more refrangible than Hα, was complex and exceedingly strong. The absorption band on the other side of Hα had an undoubtedly real existence. The presence of dark D and b lines could be positively asserted, though they were very faint. There was absorption also on the more refrangible side of Hγ. These characteristics are brought out in sketches of γ Cassiopeiæ's spectrum in Volume VI, of the *O'Gyalla Publications*.

On September 1, 1883, von Gothard saw intense Hα and Hβ emission, also Hγ and dark D but no D_3. Later neither D nor D_3 was visible. Between September 23 and November 23, the Hα, Hβ and Hγ emission lines were observed and also dark lines of the b group. D_3 continued invisible. Measures of the bright Hβ line yielded a wave-length of 4871Å.[11]

In this same period Hβ was easily seen at Greenwich. But during the following year there was evidence of continued or renewed variability. The Greenwich observations of Hβ emission in 1884 were: August 11 and 25, faint;

[9] *Monthly Notices*, Vol. 49, page 300.

[10] *Astronomische Nachrichten*, Vol. 107, page 61.
Observatory, Vol. 6, page 332.
O Gyalla Beobachtungen, Vol. 8, page 5.

[11] *Astronomische Nachrichten*, Vol. 108, page 237.

September 4, very faint; September 10, barely visible; September 11, measurable; September 18, very faint; September 20, faint, sharp, well defined at edges. These observations were made with a half-prism spectroscope attached to the 12.8-Inch Refractor.[12]

In November, 1885, O. T. Sherman announced the results of his studies of the spectrum of γ Cassiopeiæ with the 8-Inch Refractor of the Yale College Observatory. The spectroscope was a direct vision instrument with a collimator six inches long and two trains of prisms of three pieces each. In observing a star spectrum the slit was opened to 5 mm. making the star image and not the slit the source of light. Under these circumstances only rough wave-lengths could be determined and the difficulty of observation of lines at the ends of the visible spectrum must have been great. Nevertheless, Sherman gives us in addition to the hydrogen lines the wave-lengths of eleven emission and six absorption lines in this star (not including D_1 and D_2), fourteen or fifteen of which can be identified with spectral features now well substantiated. As shown in column one of Table IV, where his wave-lengths are given, Sherman observed bright Hα, D_3, Hβ, Hγ, and Hδ and also several emission lines of iron. He compared these emission lines with Young's chromospheric lines and reached the important conclusion that the number of coincidences rendered it extremely probable that the lines observed were those of the solar atmosphere.[13] The intensity of D_3 was not specified but since it was used in determination of wave-lengths it was probably clearly visible.

Observed at Dun Echt on September 3, 1885, with the 15-Inch Refractor, Hα was very bright, Hβ just measurable, while D_3 could not be made out with certainty. At the same observatory, on January 11, 1887, Hα was extremely bright.[14] Observed frequently at Kensington, between 1886 and 1894, the Hα and Hβ emission lines were always visible. On all but the third of four dates specifically mentioned (September 18, October 13 and 24, 1889; October 21, 1891) D_3 emission was also noted.[15]

In the summer of 1889, Keeler examined the spectrum of γ Cassiopeiæ frequently with a small spectroscope attached to the 36-Inch Telescope of the Lick Observatory and observed many details but no changes in its spectrum. Hα and Hβ were brilliant, narrow and sharp; Hγ was seen with some difficulty. Alternations of intensity in the green could be interpreted as bright or dark lines. Keeler seemed to favor the view that they were dark lines, the more prominent of which were identified with the b group. A fairly prominent dark band or group of lines was observed nearer to Hα than the estimated position of D, but no trace of bright or dark lines could be seen in the vicinity of D although bright D_3 was observed at Kensington on September 18 and October 13 of that year.[16] Later, at Allegheny, Keeler succeeded in photographing dark lines in the spectrum of γ Cassiopeiæ.[17]

In the meantime, in 1887 and 1888, at Greenwich, the bright lines, Hα, D_3 and Hβ, were seen apparently to continue their variations. Thus, in 1887, Hα was *not seen* while Hβ was *very distinct* on February 16, whereas, on December 5, Hα was *brilliant* and Hβ was *faint*. Eleven days later Hα was *not seen* with the cylindrical lens in place before the slit but was *distinctly seen* without the cylindrical lens. And on the same night, Hβ appeared *faint* with the cylindrical lens and was *not seen* without it. In 1888, September 19, with and without the cylindrical lens Hα was *very bright* and Hβ was rather faint. These observations were made with the single prism instrument mentioned above. On four dates in these two years there are records of observations with the half prism spectroscopes, giving much greater linear scale. In general these observations also indicate continued variation of the Hβ line. But care was necessary in the interpretation of results for on February 16, 1887, the Hβ line was *very distinct* with low dispersion, but was *very faint* and *narrow* with four fold greater power. On December 16 of the same year, when

[12] *Monthly Notices*, Vol. 49, page 300.

[13] See reference No. 3.

[14-15] *Proceedings, Royal Society of London*, Vol. 57, page 174.

[16] *Publications of the Astronomical Society of the Pacific*, Vol. 1, page 80.

[17] *Scheiner's Astronomical Spectroscopy*, Frost's translation, page 249.

instruments of high and low linear dispersion were used again, the results were accordant. Only on September 19, 1888, was D_3 seen and then as a faint emission line. Undoubtedly with attempted allowance for instrumental differences, Maunder considered that the Greenwich observations from 1880 to 1888 appeared to show: that the bright lines, $H\alpha$, D_3, and $H\beta$, in γ Cassiopeiæ varied, but not simultaneously nor similarly; that *either* $H\alpha$ or $H\beta$ was the most conspicuous line in the spectrum.[18]

In the Draper Catalogue, issued in 1890, ten photographic records of the spectrum of this star are listed. Except in three cases where the image was too dense or too near the edge of the plate, $H\beta$ was registered as a bright line.

In connection with a study of β Lyræ, Belopolsky reported the absence of D_3 from three spectrograms of γ Cassiopeiæ made in 1892. But Belopolsky's plates were probably not sensitive enough in this region to show any but the brighter lines.[19]

On November 19, 1894, J. N. Lockyer reported the results of his preliminary studies of 53 spectrograms of γ Cassiopeiæ, distributed between the dates, 1888, November 20, and 1894, November 16. His deductions may be summarized as follows: (1) Bright $H\beta$, $H\gamma$, and $H\delta$ are *constantly* seen in the Kensington photographs; $H\epsilon$ and $H\zeta$ appear when the photographic conditions have been good. (2) Additional lines, for the most part ill-defined, appear on all good negatives. (3) *During the period covered by the photographs, there is no evidence of any change in the intensities of the principal bright lines.* (4) The bright lines of hydrogen are double on all of the photographs taken with sufficient dispersion. (5) There is no evidence of (great) orbital motion from May, 1892 to November, 1894. (6) Assuming the presence of two sources of bright hydrogen lines, the relative velocity in the line of sight is 115 miles per second. (7) The bright lines of hydrogen are superposed upon broad dark bands. (8) Besides the dark bands in the positions of the hydrogen lines there are other ill-defined dark lines. (9) The dark lines in the spectrum of γ Cassiopeiæ correspond very closely with the lines seen in the spectrum of ζ and γ Orionis.[15]

In a paper[20] dated June 28, 1894, appearing late in 1895, Campbell refers to certain striking facts attested by his spectrograms. He found the hydrogen emission lines to decrease rapidly in intensity in succession toward the violet and to be situated within broad dark lines. Partially dark lines were observed in other parts of the spectrum. Further, on copies of Harvard photographs he noted many dark lines and observed that the broad dark hydrogen lines increase in intensity as they decrease in wave-length.

In her detailed discussion of the spectra of bright stars, begun in 1888, and published in 1897 (*Harvard Annals,* Volume 28, Part I), Miss Maury has made a careful analysis of the spectrum of γ Cassiopeiæ. In describing a remarkable spectrogram, taken November 23, 1892, and reproduced near the end of Volume 28 of the *Harvard Annals,* she characterized the hydrogen lines as *doubly reversed,* calling attention in this connection to Jewell's observation of complex reversals in solar lines. She noted also, as did Campbell, the diminution of intensity in each succeeding hydrogen line of shorter wave-length, $H\epsilon$ being nearly neutral and the lines of this element beyond $H\zeta$ without visible bright components. At the same time the broad underlying dark band and the narrow dark reversal became more conspicuous so far as observed. Other bright lines beside those of hydrogen were seen in the spectrum. The strongest of these, at λ 5023, was erroneously identified as an Orion line. The wave-lengths of a number of dark Orion lines were determined and these, with similar data for a number of emission lines, are found in column two of Table IV of this paper. Miss Maury states further that $\lambda\lambda$ 5015.73 and 5047.82 of helium are clearly reversed in γ Cassiopeiæ and that $\lambda\lambda$ 4026.4, 4387.8 and 4144.0 and possibly $\lambda\lambda$ 4471.8 and 4009.5 are suspected of having central narrow reversals.[21]

In the *Monthly Notices* for January, 1896, H. F. Newall reports the doubleness of $H\gamma$ and $H\beta$ clearly seen with a single-prism spectrograph.

[18] See reference No. 9.

[19] *Astronomy and Astrophysics,* Vol. 12, page 259.

[20] *Astrophysical Journal,* Vol. 2, page 177.

[21] *Harvard Annals,* Vol. 28, page 100 et seq.

In May, 1899, Sidgreaves published an extensive note on the spectrum of γ Cassiopeiæ, based on photographs distributed over a period of eight years. There were fifty-two plates, of which half were made with an eight-inch glass and half with the Perry Memorial Objective of fifteen inches aperture. Wave-lengths and intensities of a number of bright and dark lines between $H\epsilon$ and λ 5576, measured by Sidgreaves, are given in Table IV of this paper. Zero intensity for a radiation line indicates an intensity equal to that of the neighboring continuous spectrum. Sidgreaves measured a number of faint bright lines in addition to the hydrogen series and identified the group at λ 5170 with magnesium. The identity of the helium dark lines was also brought out. This investigator found no signs of variation of the hydrogen lines during the period of eight years covered by his observations, but he did suspect changes in the faint metallic emission lines, especially at $\lambda\lambda$ 4586 and 5020.[22]

In *Lick Observatory Bulletins,* Numbers 237 and 246, Merrill gave brief descriptions of results obtained from 28 plates of various parts of this spectrum, made between 1896 and 1913, with six different spectrographs attached to the 36-Inch Refractor of the Lick Observatory. On low dispersion plates of 1912, numerous faint emission lines and broad poor dark lines were recorded. Faint but unmistakable D_3 emission was noted. $H\alpha$ under high dispersion did not appear clearly reversed. Photometric intensity curves of the $H\alpha$, $H\beta$, and $H\gamma$ lines brought out in detail the structure of these lines in harmony with and in extension of published descriptions. Polarization tests of $H\beta$ led to no positive conclusions. The series contained no internal evidence of spectral variation.

In 1914, Baxandall reported the results of studies of the Kensington plates, including many which had been made since 1894. With the aid of comparisons with spectra of other stars, an extensive table of wave-lengths of dark lines in the spectrum of γ Cassiopeiæ was prepared. (See column five, Table IV.) There was distinct evidence that the chief bright lines other than those of hydrogen were identifiable with the enhanced lines of various metals, iron predominating. An intercomparison of the best of the plates obtained since 1894 showed that there were no definite changes in the spectrum on different dates.[23]

The Ann Arbor spectrograms are discussed below. It is appropriate to note here that they bring out the close qualitative correspondence of the features of this spectrum in the years, 1911 to 1915, with those of photographic observations reported by Lockyer, Campbell, Miss Maury, Sidgreaves, Merrill, and Baxandall, and further that they register no intensity variations in the spectral lines not accounted for by uncertainties of photographic contrast.

Spectral Variations. The above fairly comprehensive summary of the published observations of the spectrum of γ Cassiopeiæ is of interest especially in connection with its bearing upon the reported variations of some of the spectral features involved.

Referring first to the D_3 line of helium, the visual observations of this spectral feature would indicate that capricious changes have taken place in the intensity of this line, for it was seen distinctly by some observers and was invisible to others at or near the same epoch, and the same observer at different times, in some cases, had different impressions of its brightness. But the indications of uncertainty affecting the visual observations of the much brighter lines of hydrogen, discussed below, make very doubtful conclusions with reference to the physical reality of such observed changes. On the other hand the very fact that this line was seen so frequently by visual observers indicates that, in that period, from 1872 to 1888, it must have been stronger, at least spasmodically, than at present, for now, even photographically, it is a faint line. To be sure von Konkoly suspected and Sherman observed a number of faint emission lines in this spectrum which very possibly were then, as now, comparable in brightness with the present D_3 emission, but it seems doubtful whether so many visual observers would have recognized this line if it had been so faint as it is at the present time. In 1883, von Konkoly assigned to D_3 an intensity one-half that of $H\beta$ and one-fifth that

[22] *Monthly Notices,* Vol. 59, page 505.

[23] *Publications of the Solar Physics Committee.* "The Spectrum of γ Cassiopeiæ," 1914.

of Hα. On the Ann Arbor plates, discussed in this paper, the D_3 line is estimated to be one-fifth as bright as Hβ and one-eighth as bright as Hα. These intensity estimates may represent the extent of a possible decline in the strength of this line in a period of thirty years.

As for the faint metallic emission lines, there seems to be no evidence to show that they have undergone any secular changes like that suggested in the case of D_3, for they were seen clearly by only one visual observer, and are not recorded by others observing in the same year, and thus were very probably faint, as they are found to be at present. Even on the spectrogram their visibility is so dependent upon photographic conditions that valid conclusions as to their constancy or variation are difficult or impossible to reach. It is not strange that one photographic investigator, at least, has shifted suspicion of variability from the hydrogen to the faint metallic emission lines. But indicated variations of such lines are especially hard to establish.

For the Hα and Hβ lines, which were sometimes seen as brilliant and again as very faint or invisible with the same spectrograph, the case is clearly suggestive enough to warrant careful attention. Briefly: Secchi and Huggins saw bright Hα and Hβ in the late sixties, but Vogel, in 1872, did not find the Hα line. Then, from 1874 to 1883, no emission lines were seen by von Konkoly, notwithstanding frequent search, nor by von Gothard who looked for them often during the last two years. During this period, however, bright hydrogen emission was seen in England in 1877, 1879, 1880, and 1881. Thereafter, these emission lines were observed in Europe, at Kensington, and at the Lick Observatory, apparently without variation, but at Greenwich hydrogen emission was found to vary greatly as late as 1887, when, on December 5, Hα was brilliant, while eleven days later, with the same instrument, it was "not seen." At the same time, as seen from Greenwich, the Hβ emission continued to vary, though in no such pronounced manner. Thereafter the photographic method superseded the visual quite generally.

These visual observations were undoubtedly profoundly affected by instrumental conditions, particularly in the case of the Hα line, which is near the edge of the region for which visual objectives are corrected. Thus, on August 20, 1883, when von Konkoly did view the Hα emission after nine years of watching, it is significant that he found the line very faint when he observed it with one train of prisms, whereas with two such prism trains he found it exceedingly bright. Noteworthy, also, was the greater success which followed his observations as he employed in rapid turn telescopes of increasing aperture. Again, on February sixteenth, 1887, at Greenwich, Hβ emission was "very distinct," as seen with one spectroscope, whereas with another it was very faint; and on December sixteenth of the same year, Hα was "not seen" with a cylindrical lens before the slit, but was "distinctly seen" without such lens. Other similar cases might be cited, but without amplifying further, the conclusion seems to be indicated that the results of early visual observations of the spectrum of γ Cassiopeiæ, like those of β Lyræ, must be regarded with caution.

With the adoption of the photographic method evidence of variation of the hydrogen emission lines in the photographic region was not found and visual observations with equipment of greater average power as compared with the apparatus of the old visual observers, continued to record hydrogen emission. Later Hα was observed photographically without suspicion of variation on the following dates at least: 1911, June 21, 27, July 25, 26, 27, 28; 1912, July 30, August 1, 6, September 12, October 2; 1913, July 12, December 18; 1914, January 1, October 24; 1915, November 13; 1916, January 6. And from the hundreds of spectrograms of γ Cassiopeiæ in the photographic region, no variations in the other hydrogen lines have been announced.

In view of the absence of observed variations in the hydrogen lines after the photographic era began, it appears that an interesting comparison could be drawn if visual observations with a small refractor were available during this period. It seems that such data are reported, in 1906, by S. E. Percival of Somerset, England, as follows:

"My instrument is one of Hilger's Zöllner spectroscopes with three cylindrical lenses of different powers; the telescope is a Cooke 3¾-inch. I have been puzzled by the apparent behaviour of this (Hα) line (in γ Cassiopeiæ).

Sometimes I have seen it with great ease and distinctness, at others I have barely glimpsed it; at others again I have totally failed to see it. Thus, I saw it splendidly when the star was high up in, I think, the early days of January. On May 2, I failed to see it, but, on May 4, I saw it quite distinctly. Last night, May 18, though the sky was clear and the spectrum steady, I barely glimpsed it; sometimes indeed a *dark line* seemed to replace it."[24]

It is regrettable that no photographic observations of the Hα region were reported at this time. However, Hartmann gives a list of six spectrograms taken between July 12 and October 5 of that year (1906), and, though he characterizes the spectrum in the photographic region in general, he does not refer to variations in the intensities of the lines.[25]

Reviewing the evidence relative to the variability of features in the spectrum of γ Cassiopeiæ, it seems that we may conclude at once that, during the period from 1874 to 1884, and possibly until 1888, the variations of the hydrogen emission lines, *if real,* were of short period, as Copeland has suggested. After 1883 (or 1888) there seems to be little chance that any appreciable variation existed. In general the visual observations upon which conclusions with reference to these variations are based, were profoundly affected by instrumental conditions and must be regarded with caution. On the other hand the constancy of the photographic record must be given great weight. Further it is significant that visual observations with apparatus of limited power yielded results indicating great variations in the Hα line as late as 1906, when observers in the photographic region mention no changes. However, notwithstanding the evidence tending to discredit the work of the early visual observers, it would seem that the time has not come to reject the results gathered by them in connection with the much discussed variations of the hydrogen lines in the spectrum of γ Cassiopeiæ. But astronomers at the present time will hesitate to regard the reality of these variations as established until confirmation is found through the photographic method.

[24] *Journal British Astronomical Association*, Vol. 16, page 319.

[25] *Astronomische Nachrichten*, Vol. 173, page 102.

FORMER RADIAL VELOCITIES.

Radial velocities of γ Cassiopeiæ have been announced by Vogel and Scheiner on page 99 of *Potsdam Publ.*, Vol. VII, by Hartmann on page 102 of *Astronomische Nachrichten*, Volume 173, and by Merrill on pages 163 and 164 of *Lick Observatory Bulletin*, Number 237.

The observations of Vogel and Scheiner were:

1888, October 6,	+ 0.8 km.
1889 January 9,	− 7.8
Mean velocity,	− 3.5

Hartmann found the lines in this spectrum hard to measure because of their diffuseness. Also he thought that there were relative shifts among the lines. The velocities correspond to measures of the middle of the lines, which were in general of symmetrical structure. These nine velocities with their mean are given in Table II. Considering the velocity of the star as constant, the probable error of a single observation of Hartmann proves to be ± 4.6 km., which is in close accord with his idea of the accuracy of the several velocities. Nevertheless, Hartmann considered that the apparent slow change in the radial velocity of this star was real and announced it as an object with variable radial velocity, adding the suggestion that more definite information with reference to the nature of the variation would be obtained through observations extending over a long time interval. Possibly the reader will have misgivings as to the safety of this announcement.

TABLE II. THE POTSDAM OBSERVATIONS.

SPECTROGRAPH	DATE	VELOCITY	RESID.
I	1900, July 2	+ 0.5 km	+ 9.0 km
I	Sept. 21	+ 3.1	+11.6
I	1901, Sept. 27	−19.3	−10.8
III	1906, July 12	−10.1	− 1.6
I	17	− 5.8	+ 2.7
I	Sept. 22	− 9.3	− 0.8
I	24	−14.4	− 5.9
I	30	−10.0	− 1.5
I	Oct. 5	−11.1	− 2.6
	MEAN	− 8.5	

The sixteen observations made at the Lick Observatory are conveniently divided into four groups depending on the spectrograph used, the measurer and the features measured. The entire series extends over sixteen years and each set centers about a well defined epoch. The means of the four groups are all nearer to zero than Hartmann's mean, but the mean for the third and strongest group differs only two kilometers from that of Hartmann. In his *Second Catalogue of Spectroscopic Binary Stars,* containing data available up to March 15, 1910, Campbell noted that the Lick Observatory observations did not confirm Hartmann's announcement. Considering the twenty-seven velocities of γ Cassiopeiæ derived at Potsdam and the Lick Observatory, the conclusion is reached that more observations would be necessary to establish the reality of Hartmann's reported velocity variation.

TABLE III. THE LICK OBSERVATORY OBSERVATIONS.

SPECTROGRAPH	MEASURER	FEATURE MEASURED	G. M. T.	VELOCITY
			1896	
Original Mills.	Campbell.	Bright components Hγ Emission.	Aug. 9.99	— 1 km
			19.00	— 1½
			Sept. 23.86	— 4
			Nov. 11.78	— 4
			MEAN	— 2.6
			1903	
Remounted Mills.	Moore.	Bright components Hγ Emission and central absorption.	Nov. 1.96	— 1½
			1.98	— 4
			MEAN	— 2.8
			1910	
Same.	Merrill.	Same.	Nov. 14.68	— 2.4
			15.84	— 7.3
			17.59	— 6.2
			1911	
			Jan. 7.61	± 0.0
			Aug. 7.93	—10.5
			Nov. 23.76	— 9.6
			24.77	— 8.8
			MEAN	— 6.4
			1912	
Three-Prism, λ4900 central.	Merrill.	Hβ Line.	Aug. 21.94	— 2.9
			22.92	— 7.6
			29.90	+ 2.7
			MEAN	— 2.6

DETROIT OBSERVATORY STUDIES.

Material. The writer's studies of γ Cassiopeiæ are based upon seventy-four spectrograms made in the years, 1911 to 1914, with the single-prism spectrograph described in Volume I of these *Publications*. Seventy of these spectrograms are listed in Table VI and four more are referred to in the foot note following that table. With a

few exceptions the negatives were made with Red Label Lantern Slide Plates. Three plates were sensitized to visual light. Two plates, made with a very long slit, were especially useful in the study of faint wide absorption lines.

Wave-Lengths and Intensities of Lines. The wave-lengths, intensities, number of measures and relative weights for the lines in the spectrum of γ Cassiopeiæ, observed at Ann Arbor, are found in the four columns next to the last in Table IV. The preceding columns contain parallel or additional results obtained by Sherman, Miss Maury, Sidgreaves, and Baxandall for the photographic region, and by Sherman, Sidgreaves, and Merrill for the visual region of the spectrum. The last column contains laboratory wave-lengths, identifications, symbols, and remarks for many of the lines. In this column the wave-lengths for the metallic emission lines, except those in the visual region observed by

TABLE IV. ASSEMBLED WAVE-LENGTHS OF LINES IN THE SPECTRUM OF GAMMA CASSIOPEIAE.

SHERMAN	MAURY	SIDGREAVES		BAXANDALL	CURTISS				IDENTIFICATIONS, ETC.
WAVE-LENGTH (1) Å	WAVE-LENGTH (2) Å	WAVE-LENGTH (3) Å	INT. (4) Å	WAVE-LENGTH (5) Å	WAVE-LENGTH (6) Å	INT. (7)	NO. (8)	WT. (9)	(10)
......	......	......	....	......	3888.81E	6	2	2	3889.20, Hζ.
......	......	......	....	3889.1	3888.80	4n	2	2	3889.20, Hζ.
......	3912.2	......	....	......	....	...	..	..	....
......	......	......	....	3920	3920.0	5	1	1	Blend. N, O, C.
......	3927.1	......	....	3926.7	3927.4	4nn	1	1	3926.7, Helium.
......	......	......	....	......	3930.4	8	1	1	....
......	......	......	....	3933.8	3933.86	3.6	39	27	3933.83, K Calcium.
......	......	......	....	......	3935.7	5	1	1	3936.06, Helium.
......	......	3970E	0	......	3970.19E	14	7	4	3970.18, Hε.
......	......	......	....	3970.2	3970.26	3.5	30	22	3970.18, Hε.
......	......	3983	1	......	....	...	..	..	....
3993	3994.9	3995	2	3995.2	3995.8	4	1	1	....
......	......	......	....	......	3998.0	6	1	1	....
......	4009.5	4009	5	4009.4	4009.6	6	7	5	4009.42, Helium.
......	......	......	....	......	4010.7	8	3	1	....
......	......	......	....	......	4011.4	5	2	2	....
......	4026.4	4025	6	4026.3	4026.56	12n	53	28	4026.37, Helium.
......	......	4037	1	......	....	...	..	..	....
......	......	4043	1	......	....	...	..	..	....
......	......	......	....	......	4065.4E	4	2	2	....
......	......	......	....	......	4067.2	4	3	4	4067.22, β Lyræ.
......	4069.4	4069	3	......	4069.5	4	2	1	....
......	......	......	....	......	4071.5	5	4	2	....
......	4072.0	4076	2	4073.–	4073.4	5	3	2	Oxygen Triplet.
......	4089.2	4088	1	4089.2	4089.7	7n	1	1	4089.00, Si.
Obs.	Obs.	4101E	2	......	4101.92E	20	48	42	4101.92, Hδ.
......	......	......	....	4101.8	4101.90	3.1	60	68	4101.92, Hδ.
......	4116.2	......	....	4116.5	....	...	..	..	Silicon.
......	......	4118	3	......	4118.8	8n	2	2	Blend. Si and He.
......	4120.5	......	....	4121.0	....	...	..	..	Helium.

TABLE IV. ASSEMBLED WAVE-LENGTHS OF LINES IN THE SPECTRUM OF GAMMA CASSIOPEIAE—Continued.

SHERMAN	MAURY	SIDGREAVES		BAXANDALL	CURTISS				IDENTIFICATIONS, ETC.
WAVE-LENGTH (1) Å	WAVE-LENGTH (2) Å	WAVE-LENGTH (3) Å	INT. (4) Å	WAVE-LENGTH (5) Å	WAVE-LENGTH (6) Å	INT. (7)	NO. (8)	WT. (9)	(10)
......	......	4131E	3	......	....	...	..	..	....
......	......	......	....	......	4141.21	3	2	2	....
......	4144.0	4144	4	4143.9	4144.1	8n	8	5	4143.92, Helium.
......	......	......	....	......	4145.9	5	3	2	....
......	......	4155	1	4155.0	....	...	..	..	Blend, Oxygen.
......	......	4170	3	4169.1	4169.3	9n	2	2	4169, Helium.
4180E	......	4177E	2	......	4177.4E, A	3	2	2	4177.70, Fe-V 12.
......	......	4185	2	......	....	...	..	..	....
......	......	......	....	......	4200.2	4	1	1	4200.3, Hδ′.
......	......	......	....	......	4207.4E	5	3	2	....
......	......	......	....	......	4214.6E	3	1	1	4215.9, Sr 40.
......	......	4234E	2	......	4233.60E	5.0	22	16	4233.33, Fe-Cr 20.
......	......	......	....	......	4233.41	3.0	15	13	4233.33, Fe-Cr 20.
......	......	4239	1d	......	....	...	..	..	....
......	4254.1	4253	1	4253.8	....	...	..	..	....
......	......	......	....	......	4260.11E	4.0	7	4	4260.23, Fe 2. 4260.64, Fe 8.
......	4267.4	4266	1	4267.4	4267.5	7n	1	1	4267.15, Carbon.
......	......	......	....	......	4271.8E	5	2	2	4271.32, Fe 6. 4271.93, Fe 15
......	......	4281	2w	......	4282.1	4	2	1	....
......	4285.1	......	2	4285.1	....	...	..	..	Sulphur.
......	......	4295	2	......	4295.4	8	1	1	....
......	......	4302E	2	......	....	...	..	..	....
......	......	4306	2	......	4307.8	4	4	4	....
......	......	4317	1	4318.–	4317.8	10n	1	1	Oxygen pair.
......	......	4326	1	......	....	...	..	..	....
Obs.	Obs.	4340E	8	......	4340.64	24	69	77	4340.63, Hγ.
......	Obs.	Obs.	—	......	4340.66	2.5	55	57	4340.63, Hγ.
......	......	......	....	......	4353.3E	4	4	2	4352.9,? Fe 4.?
......	......	......	....	4367.0	4367.4	7n	1	1	4367.—, Oxygen.
......	......	4382E	1	......	4384.25E	5.0	21	14	4383.72, Fe 15. 4385.55, Fe 5.
......	......	......	....	......	4384.61	3	7	5	4383.72, Fe. 15. 4385.55, Fe 5.
......	4387.8	4388	4	4388.1	4388.3	5	8	5	4388.10, Helium.
......	......	......	....	......	4390.9	4	5	4	....
......	......	4395E	2	......	....	...	..	..	....
......	......	......	....	......	4400.5	3	2	1	....
......	......	......	....	......	4403.07	4	4	3	....

TABLE IV. ASSEMBLED WAVE-LENGTHS OF LINES IN THE SPECTRUM OF GAMMA CASSIOPEIAE—CONTINUED.

SHERMAN	MAURY	SIDGREAVES		BAXANDALL	CURTISS				IDENTIFICATIONS, ETC.
WAVE-LENGTH (1) Å	WAVE-LENGTH (2) Å	WAVE-LENGTH (3) Å	INT. (4) Å	WAVE-LENGTH (5) Å	WAVE-LENGTH (6) Å	INT. (7)	NO. (8)	WT. (9)	(10)
......	......	......	....	4416	....	...	..	..	Oxygen.
......	......	......	....	......	4418.8E	4	1	1	....
......	......	......	....	......	4418.8	2	1	1	....
......	......	4431	3	......	....	...	..	..	....
......	......	......	....	4437.7	....	...	..	..	Helium.
......	......	4451	1	......	....	...	..	..	....
......	......	4462E	1	......	4462.22E	3	2	2	....
......	......	......	....	......	4469.39	7	6	3	....
......	4471.8	4471	6	4471.7	4471.8	5	6	5	4471.68, Helium.
......	......	4481E	2	......	4481.6	3	8	8	4481.40, Magnesium.
......	......	4485	1	......	4484.21	3	2	2	....
......	......	......	....	......	4491.46E	4	4	3	4491.57, Fe 6.
......	......	......	....	......	4491.5	2	1	1	4491.57, Fe 6.
......	......	4518E	3	......	4521.8E	3	3	3	4520.40, Fe 8. 4522.83, Fe-Ti-Eu 12
......	......	......	....	......	4557.5E	4	6	4	....
......	4568.6	......	....	......	....	...	..	..	....
......	......	4573	4w	......	4571.5	5	1	1	....
......	......	4586E	6n	......	4583.76E	5.7	34	26	4584.02, Fe-V 15.
......	......	......	....	......	4583.93	2.8	27	19	4584.02, Fe-V 15.
......	......	4596	3	......	....	...	..	..	....
......	......	4612	3	......	....	...	..	..	....
4623E	......	4628E	3	......	4629.3E	6	7	4	4629.52, Fe-Co 12.
......	4641.0	......	....	......	4640.7	5	3	3	....
......	4649.2	4647	6w	......	4649.9	5	3	2	4649.5, Carbon.
......	......	......	....	......	4651.0	11	22	12	Blend.
......	......	......	....	......	4653.1	4	3	2	....
......	......	......	....	......	4657.0E	7	12	6	....
......	4661.7	......	....	4661.8	4662.3	6	10	6	Oxygen.
......	......	4664E	4n	......	4668.4E	6	8	4	....
4673.5	4675.3	......	....	4676.3	....	...	..	..	Oxygen.
......	4685.4	4681	3n	4686.0	4685.8	6	1	1	4685.98, Hydrogen.
......	4712.8	4711	1	4713.3	4713.4	5	2	2	4713.31, Helium.
Obs.	Obs.	4861E	10	4861.5	4861.51E	24	71	80	4861.53, Hβ.
......	......	......	....	......	4861.58	1.3	8	7	4861.53, Hβ.
4920E	......	......	....	......	4925.7E	5	3	2	4924.11, Fe 20.
4990	......	5006	3	......	....	...	..	..	....
5020	5023E	5020E	4d	......	5018.3E	4	5	4	5018.63, Fe 15.
......	......	......	....	......	5018.1	4	4	4	5018.63, Fe 15.

TABLE IV. ASSEMBLED WAVE-LENGTHS OF LINES IN THE SPECTRUM OF GAMMA CASSIOPEIAE—CONTINUED.

THE VISUAL REGION.

SHERMAN	SIDGREAVES		MERRILL	CURTISS				IDENTIFICATION, ETC.
WAVE-LENGTH (1) Å	WAVE-LENGTH (2) Å	INT. (3)	WAVE-LENGTH (4) Å	WAVE-LENGTH (5) Å	INT. (6)	NO. (7)	WT. (8)	(9)
5020	5020E	4d	5018.4E	5018.3E	4	2	2	5018.63, Fe 20
......	5048	2	......	5048	7	2	2	....
......	5104	2	......	5106	8n	1	1	....
......	5160	3	......	5162	4	2	2	....
5167.5E	5170E	4	5169.0E	5169E	6	3	3	5167.68, Fe —, b_4.?
......	......	..	......	......	..	..	..	5169.16, Fe 15, b_3.?
......	......	..	......	5168	2	1	1	Reversal.
......	......	..	......	5174	4	1	1	5172.9 ?, b_2.?
......	......	..	......	5180	5	2	2	....
......	......	..	......	5186E	3	1	1	5183.8 ?, b_1.?
......	5214	3n	......	5214E	3	2	1	....
......	......	..	......	5234E	4	2	1	5234.8 — 10, Young.
......	5256	3n	......	......	..	..	..	....
......	......	..	......	5278E	3	3	2	5276.15, Cr—Fe 10.
......	......	..	......	5281	5	2	2	....
......	......	..	......	5286E	3	2	1	....
......	5295	4n	......	5294	6	2	1	....
5309.8E	5316E	2	5316.4E	5317E	4	3	3	5316.86, Fe—Co 12.
......	......	..	......	5327E	2	1	1	Blend of Fe lines.
......	5350	4n	......	5355	10	1	1	....
......	5376	3	......	5376	7	2	2	....
......	5411	3	......	......	..	..	..	....
5422E	......	..	......	5426E	3	2	1	5429.91, Fe 10.
......	5524	3	......	5523	5	2	2	....
5557.5E	5540E	2	......	5537E	4	1	1	5535.07, Fe 12, Young.
......	5576E	2	......	......	..	..	..	....
5760	......	..	......	5760	5	1	1	....
......	......	..	......	5852	6	2	1	....
Obs.	......	..	Obs.	5876E	5	3	3	5875.87, Helium D_3.
......	......	..	......	5882	6	2	1	....
6160E	......	..	......	6149E	4	1	1	Blend, Fe 5, Young.
6280	......	..	......	6278	12	3	2	....
......	......	..	......	6307	6	3	3	....
......	......	..	......	6320E	4	2	2	6318.2, Fe—Ca 3, Young.
......	......	..	......	6340	9	1	1	....
6356E	......	..	......	6350E	4	1	1	....
......	......	..	......	6367	6	2	2	....
Hα	......	..	Hα	Hα	40	4	—	6563.

Young, are due to Rowland, the intensities to S. A. Mitchell, as observed by him in the flash spectrum. The other wave-lengths were obtained from various sources. The letter E, following a wave-length, marks an emission line; the letter A, an absorption line. Wave-lengths with no letters following correspond also to absorption lines.

The wave-lengths in Table IV are based on the assumed values for the lines, Hδ, Hγ, and Hβ, given in the last column of this table. For the better determined lines the probable errors resulting from comparison among the values from the different plates are given in Table V. Uncertainties in the interpolation curve employed and in the assumed wave-lengths would increase these probable errors by a few hundredths of an angstrom.

TABLE V. WAVE-LENGTHS AND PROBABLE ERRORS OF SELECTED LINES.

LINE	CORRECTED WAVE-LENGTH Å	PROBABLE ERROR Å
K	3933.86 A	± 0.028
Hε	3970.19 E	± 0.060
Hε	3970.26 A	± 0.036
He	4026.56 A	± 0.027
Hδ	4101.92 E	± 0.017
Hδ	4101.90 A	± 0.014
Hγ	4340.64 E	± 0.009
Hγ	4340.66 A	± 0.013
Fe	4583.76 E	± 0.058
Fe	4583.93 A	± 0.065
Hβ	4861.51 E	± 0.013
Hβ	4861.58 A	± 0.058

The identifications suggested in Table IV for the emission lines seem well established. That these emission lines, probably without exception, correspond to strong chromospheric lines is well brought out. The marked prominence of iron emission in these lines is also evident.

In view of the references of early observers to the presence of the b group of magnesium in the spectrum of γ Cassiopeiæ, the data in Table IV referring to this region are of some interest. There seems to be no question as to the presence of an iron emission line at λ 5169.16 Å; and since this line is normally about six angstroms wide, b_1, b_3, and possibly b_2, if present, would be blended or lost in it. Probably also the emission line, b_1, is included in the emission line measured at λ 5186 in such a way that it can not be distinguished if it exists. It is possible then that magnesium emission does contribute to the lines which have been observed at λ 5169 and λ 5186. But in that case we would expect to find at least the first of these lines exceptionally wide, whereas the measured width of 6.6 Å exceeds the normal width of 6.1 Å, taken from Plate II, by a relatively small amount. Sidgreaves considered that the identification of λ 5169 Å as a magnesium group was confirmed by the existence of λ 4481 Å of this element as an emission line in the spectrum of this star. However I have not been able to find this emission line on my plates. Keeler inclined to the belief that the b group was dark in this spectrum. Aside from the occurrence of an absorption line at λ 5174 Å, which might involve b_2, there seems to be no evidence gained from the plates of this Observatory in support of this idea. It seems probable that the b group of magnesium is not present in this spectrum.

The line intensities assigned by Sidgreaves and the writer are based on scales so different that intercomparison is not readily made. The writer's intensity numbers are based on the scale used in his previous papers. In general these numbers for absorption lines are several times those assigned by Sidgreaves, but discrepancies occur which suggest differences in interpretation of the observed features. For the emission lines Sidgreaves has based his intensities on the excess of density over that of the neighboring continuous spectrum. Thus the wide band at Hε is assigned intensity zero. The writer has estimated his intensities of emission lines on the basis of their extent and density, assuming that they are superposed upon absorption as the line structures indicate. The two systems lead to widely different results making numerical comparison difficult.

The wide absorption lines in the spectrum of γ Cassiopeiæ are too weak and ill-defined to permit of discriminating studies of intensity

TABLE VI. THE ANN ARBOR OBSERVATIONS.

NO. OF PLATE	DATE, G. M. T.	Hδ, Hγ, AND Hβ LINES				E—A		EMISS. INT.			EMISSION WIDTH		
		VEL.	RESID.	NO.	WT.	VEL.	WT.	Hδ	Hγ	Hβ	Hδ	Hγ	Hβ
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	1911 d	km.	km.			km.					Å	Å	Å
134	July 17.895	+ 1.1	+ 8.4	4	4	— 3	1	15	22	25	4.01n	4.31S	5.56s
197	Aug. 30.812	— 9.7	— 2.4	5	8	± 0	4	..	..	25	3.92W	4.31w	5.83w
198	30.830	— 5.4	+ 1.9	5	5	+ 2	2	..	25	20	3.99n	4.46s	5.48n
199	30.841	— 9.0	— 1.7	5	8	± 0	3	..	25	20	......	4.84n	5.18w
200	30.855	— 9.6	— 2.3	5	8	— 1	3	20	25	25	3.89n	4.01s	5.03w
210	Sept. 19.797	— 6.0	+ 1.3	2	2	....	..	..	20	25	......	4.29s	5.12n
211	19.803	—13.7	— 6.4	5	5	+ 3	2	15	25	25	3.95w	4.05n	5.24w
212	19.815	— 1.8	+ 5.5	5	5	+ 3	2	20	25	20	3.71W	4.18w	4.77W
214	22.836	—14.5	— 7.2	5	7	+ 6	3	25	25	20	3.86w	4.10n	4.29W
215	22.848	— 6.0	+ 1.3	5	6	— 9	2	18	25	25	3.80s	4.24S	4.77w
221	23.824	—10.9	— 3.6	5	6	+ 7	2	25	25	25	4.07w	4.31n	4.85w
222	23.835	—10.6	— 3.3	5	5	— 1	2	15	20	25	4.31s	4.41S	5.51n
229	27.809	— 2.4	+ 4.9	4	4	+ 4	1	..	20	25	......	4.07s	4.71n
230	27.820	—12.2	— 4.9	4	4	— 16	1	..	25	25	......	4.31s	4.71n
235	Oct. 2.757	—10.6	— 3.3	3	2	— 3	1	..	20	22	......	4.39n	4.94w
236	2.771	— 1.7	+ 5.6	3	3	— 7	1	..	20	20	......	4.14w	4.65W
241	7.784	—11.6	— 4.3	4	4	— 3	1	..	20	20	......	4.01w	4.94W
242	7.792	— 6.6	+ 0.7	5	7	+ 6	2	25	20	20	4.01w	4.31w	4.50W
246	11.762	— 6.6	+ 0.7	4	4	— 6	1	18	25	25	4.25n	4.14n	5.36w
247	11.772	—11.5	— 4.2	4	4	+14	1	16	25	25	3.96n	4.45s	5.27w
254	13.657	—10.3	— 3.0	3	3	— 2	2	..	20	25	......	4.48s	5.21w
255	13.679	—15.–	— 7.–	1	1	....	..	..	..	25	......	......	5.62s
264	18.759	— 3.2	+ 4.1	5	5	— 7	2	20	20	25	3.38n	4.37s	5.00w
265	18.765	— 0.7	+ 6.6	4	6	—12	2	20	25	18	4.38w	4.64n	5.36w
282	27.727	—10.9	— 3.6	4	3	—16	1	15	20	25	3.98w	4.28w	5.48w
283	27.732	— 7.3	± 0.0	5	5	— 5	2	16	25	25	4.02n	4.31n	5.15w
	1912												
1108	Sept. 26.785	+ 0.4	+ 7.7	4	4	± 0	1	..	20	25	......	4.31n	5.33n
1447	Nov. 10.726	—16.6	— 9.3	2	1	....	..	..	20	25	......	4.62S	5.56s
1448	10.747	—12.0	— 4.7	4	4	+ 9	1	..	25	25	3.99n	4.33s	5.33w
1507*	27.638	— 9.0	— 1.7	4	3	+ 3	1	..	20	25	3.80s	4.18S	5.51S
1508*	27.646	—11.–	— 4.–	1	1	....	..	..	..	25	......	......	5.62S
1530	30.620	— 7.1	+ 0.2	3	3	....	..	16	25	25	3.89n	4.69n	4.71w
1531	30.632	— 5.9	+ 1.4	5	8	+ 3	3	20	..	20	4.51w	4.45w	4.47w
1537*	Dec. 4.662	— 3.6	+ 3.7	5	4	— 1	3	20	20	25	3.81n	4.79n	4.88w
1538*	4.667	—16.0	— 8.7	5	5	+12	2	20	20	22	4.01n	4.48n	4.88w
1540	Dec 7.552	— 3.2	+ 4.1	4	4	± 0	2	20	20	25	3.78n	4.24s	4.97n
1541†	7.560	—14.7	— 7.4	4	3	— 2	2	..	30	20	......	4.65n	5.36w
1544	8.592	—10.9	— 3.6	5	5	— 1	2	20	20	18	4.05w	4.37w	5.06w
1545	8.615	— 4.8	+ 2.5	3	4	— 9	1	..	30	25	......	4.07w	5.39W
1550*	11.660	— 2.0	+ 5.3	5	7	+ 2	3	..	25	20	3.87w	4.05n	4.68W

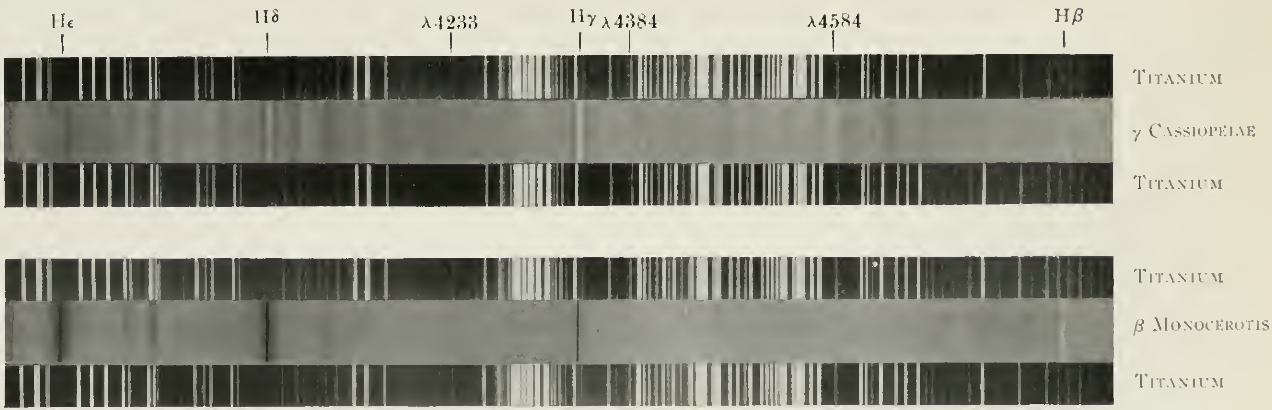

Plate C. Spectra of the Stars, Gamma Cassiopeiae, 1914, Feb. 19, and Beta Monocerotis, 1914, Nov. 22, with Titanium Spark Comparison

TABLE VI. THE ANN ARBOR OBSERVATIONS—CONTINUED.

NO. OF PLATE	DATE, G. M. T.	Hδ, Hγ, AND Hβ LINES				E—A		EMISS. INT.			EMISSION WIDTH		
		VEL.	RESID.	NO.	WT.	VEL.	WT.	Hδ	Hγ	Hβ	Hδ	Hγ	Hβ
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	1912 d	km.	km.			km.					Å	Å	Å
1552	14.610	—10.6	— 3.3	4	4	....	..	25	25	25	3.93n	4.56s	5.12n
1553†	14.615	—15.2	— 7.3	5	4	+ 3	1	20	25	25	3.95s	4.75S	4.88n
1564	22.602	— 5.7	+ 1.4	5	8	+ 1	3	25	25	20	......	4.65w	4.65W
1565	22.606	—10.2	— 2.9	4	4	+ 5	1	..	30	20	......	4.16n	5.00w
	1913												
1572	Jan. 12.600	— 9.5	— 2.2	4	4	— 8	1	..	25	20	......	4.46w	4.85W
1573	12.621	— 8.5	— 1.2	5	6	— 4	3	30	25	20	4.08w	4.71n	4.56w
1574	12.626	— 3.3	+ 4.0	4	4	+ 6	1	..	20	25	......	4.20w	5.12w
1600	Feb. 8.587	—16.0	— 8.7	5	6	+13	2	20	25	25	4.51w	4.39n	5.62w
1601	8.603	—13.1	— 5.8	4	4	—22	1	..	20	20	......	4.16w	4.44W
2244	Aug. 24.833	— 6.4	+ 0.9	5	5	+ 2	2	20	25	28	3.53s	4.64s	5.42n
2245	24.843	— 6.4	+ 0.9	4	4	—11	1	..	25	25	......	4.41s	4.53w
2351*	Oct. 4.703	—13.3	— 6.0	2	2	....	..	..	22	25	......	4.52n	5.24w
2352‡	4.715	— 5.8	+ 1.5	5	4	+ 3	2	20	25	25	4.02n	4.41n	4.82w
2362	9.672	— 1.4	+ 5.9	4	3	— 9	1	..	20	20	......	4.26n	4.77w
2363	9.687	— 9.0	— 1.7	5	7	± 0	3	25	30	25	3.68n	4.43n	5.33w
2378	12.720	— 2.9	+ 4.4	5	6	+ 1	2	16	25	25	4.01n	4.39s	4.85n
2379	12.739	— 4.6	+ 2.7	5	5	+ 4	2	18	20	25	4.19n	4.50s	4.71n
2394	18.679	— 6.3	+ 1.0	4	4	....	..	..	30	20	......	4.62n	4.56w
2395	18.698	+ 6.7	+14.0	5	5	—17	1	25	25	25	......	4.90s	5.56n
2396	18.758	— 6.5	+ 0.8	4	3	— 6	1	..	25	15	......	4.62w	4.71w
2402	25.720	—15.9	— 8.6	4	2	+19	1	25	30	30	......	......	5.27s
2403	25.740	+ 0.5	+ 7.8	5	6	+ 2	2	25	25	25	3.86w	4.16n	5.42w
2414	Nov. 1.677	— 5.1	+ 2.2	5	6	+ 4	3	15	40	30	3.56n	4.64n	5.74w
2415	1.695	— 0.5	+ 6.8	4	5	± 0	3	..	25	25	......	4.09n	4.56w
2524	Dec. 27.598	— 9.7	— 2.4	5	7	± 0	3	20	30	20	4.02w	4.48n	4.68W
2525	27.621	—14.4	— 7.1	5	5	+10	2	25	25	25	3.62n	4.12s	5.49w
	1914												
2530	Jan. 1.555	— 3.4	+ 3.9	5	7	—12	3	16	30	25	3.68w	4.62n	4.94n
2564	Feb. 5.604	— 3.0	+ 4.3	2	2	....	..	..	20	..	......	4.35n	5.03n
2583	19.570	— 9.7	— 2.4	3	3	—16	2	25	..	25	3.75s	......	5.42w
2584	19.583	+ 1.0	+ 8.3	5	8	+ 5	4	20	25	20	3.64w	4.58w	4.82W

In addition to the spectrograms listed above, there were used in wave-length determination: Plates 2511, of 1913, December 18; 3037, of October 24, 1914; 3077 and 3078, of December 31, 1914. Plates 2511, 2564 and 3037 were sensitized to visual light. Plates 3077 and 3078 were made with a long slit giving a wide spectrum similar to that usually made with the objective prism. Plates with numbers followed by asterisks (*) in column one were made by Mellor, single daggers (†) by Lindsay, double dagger (‡) by Merrill. All the remaining plates were made by Curtiss.

variations. Indeed in a long series of plates a relatively small number will be found to have the nice combination of photographic conditions necessary to bring these lines out. The metallic emission lines are also not well adapted to intensity studies, since their edges are often not clearly marked and in density they exceed the continuous spectrum but little. On the other

hand the emission and central absorption components of Hδ, Hγ, and Hβ are fairly suitable for studies of intensity changes.

In columns nine, ten and eleven of Table VI the writer's estimates of the intensities of the emission lines of Hδ, Hγ, and Hβ are given for each spectrogram. A glance will show that some range exists among the estimates of any one line, but such variations appear between plates made in rapid succession on the same night. Evidently the variations found here are ascribable to uncertainties of photographic registration and of intensity estimates. On the other hand these estimates do indicate that no great variations, such as those reported by visual observers, are recorded on these plates. Further, in Table VII,

TABLE VII. MEAN INTENSITY OF HYDROGEN EMISSION LINES.

YEARS AND MONTHS	INTENSITIES					
	Hζ	Hε	Hδ	Hγ	Hβ	Hα
1911, July–Oct.	..	..	19	23	23	..
1912, Sept.–1913, Feb.	..	..	21	24	23	..
1913, Aug.–1914, Feb.	..	..	21	25	24	..
1911–1914	6	14	20	24	23	40

where the intensity estimates are grouped into means by seasons, there appears no evidence of appreciable change in the average intensities of these emission lines from year to year.

The mean intensities for all hydrogen emission lines, in the last line of Table VII, bring out the well known increase of intensity of these lines from Hζ to Hα, the apparent exception in the case of Hβ being due to the decreased sensitivity of lantern slide plates in this region. This increase in intensity of hydrogen emission with wave-length would be still more marked here if the excess of brightness over that of the neighboring continuous spectrum had formed the basis of intensity estimates as in the case of former observations.

The individual intensity estimates for the central hydrogen absorption and for the absorption lines, K and λ 4026, which were measured many times on these plates, are not reproduced here. It is sufficient to say that they do not support any hypothesis of variation. The means by years and the final means are found in Table VIII The decrease in intensity of the central hydrogen absorption with increasing wave-length is well brought out though to some extent the effect of varying dispersion is involved here. There seems to be no evidence of marked intensity variations in the same line from year to year.

In view of the suspicion, expressed by Sidgreaves, of variation in the intensities of metallic emission lines in the spectrum of γ Cassiopeiæ, interest will be heightened in a tabulation of the data of the Ann Arbor spectrograms bearing on this point. In Table IX, have been collected the estimated intensities, on the scale employed for the hydrogen lines, of the emission and central absorption lines of λλ 4233, 4384 and 4584, the latter of which was mentioned specifically by Sidgreaves. Evidently there is no indication of real variation here from plate to plate and no certain indication of change from year to year. Apparently if these lines do vary, the range must be small or the period long; or possibly the fluctu-

TABLE VIII. MEAN INTENSITIES OF CENTRAL HYDROGEN ABSORPTION, K AND λ 4026.

YEARS AND MONTHS	INTENSITIES						
	Hζ	Hε	Hδ	Hγ	Hβ	K	λ4026
1911, July–Oct.	...	3.3	3.1	2.4	1.–	3.7	12.2
1912, Sept.–1913, Feb.	...	3.8	3.4	2.8	1.3	3.8	11.4
1913, Aug.–1914, Feb.	...	3.5	2.9	2.5	1.4	3.4	12.2
1911–1914	4.–	3.5	3.1	2.5	1.3	3.6	11.9

TABLE IX. INTENSITIES OF METALLIC EMISSION AND ABSORPTION LINES.

PLATE	DATE G. M. T.		λ 4233 INTENSITY		λ 4384 INTENSITY		λ 4584 INTENSITY	
			EMISS.	ABS.	EMISS.	ABS.	EMISS.	ABS.
	1911							
198	August	30.83	5	2.5	5	...	5	3.5
199		30.84	6	...	4	...	5	3
200		30.85	5	2	4	...	7	2
211	September	19.80	...	...	...	...	...	5
212		19.81	...	...	5	3	8	4
214		22.84	4	...	...	...	6	...
221		23.82	5	...	7	2	6	...
229		27.81	...	...	...	...	5	2
230		27.82	...	3	...	...	5	2.5
236	October	2.77	...	3.5	...	...	...	...
242		7.79	6	3	5	3	5	...
264		18.76	...	...	...	...	6	2
265		18.77	...	...	8	...	...	...
283		27.73	...	...	...	...	...	2
	1911 MEAN		5.2	2.8	5.4	2.7	5.8	2.9
	1912							
1108	September	26.78	...	...	...	...	5	2
1530	November	30.62	...	...	...	...	5	3
1531		30.63	5	3.5	...	...	5	2
1538	December	4.67	...	3.5	...	...	...	...
1540		7.55	...	...	...	...	5	2
1541		7.56	...	...	...	...	5	...
1544		8.59	7	2.5	4	...	5	...
1545		8.61	5	...	...	...	5	...
1550		11.66	5	...	...	...	8	3
1552		14.61	...	...	...	...	5	...
1564		22.60	5	5	4	...	6	3
1565		22.61	5	2	...	...	...	...
	1913							
1572	January	12.60	...	...	5	...	5	2
1573		12.62	5	...	5	...	8	...
1574		12.63	4	2	4	3	5	3
1600	February	8.59	...	2.5	5	...	8	4.5
1601		8.60	4	4	4	4	4	3
	1912-1913 MEAN		5.0	3.1	4.4	3.5	5.6	2.8
2244	August	24.83	...	2.5	...	...	...	...
2245		24.84	...	...	...	...	6	3
2351	October	4.70	...	3.5	...	...	...	...
2363		9.69	5	...	5	...	5	2
2394		18.68	...	...	5	...	...	...

TABLE IX. INTENSITIES OF METALLIC EMISSION AND ABSORPTION LINES.
CONTINUED.

PLATE	DATE G. M. T.		λ 4233 INTENSITY		λ 4384 INTENSITY		λ 4584 INTENSITY	
			EMISS.	ABS.	EMISS.	ABS.	EMISS.	ABS.
2300	October	18.76	...	...	...	...	5	...
2414	November	1.68	6	3	...	...	...	...
2524	December	27.60	6	...	5	...	6	...
2525		27.62	...	...	6	...	6	3
	1914							
2530	January	1.56	5	3	5	2.5	5	3
2584	February	19.58	6	...	5	...	5	2.5
	1913-1914 MEAN		5.6	3.0	5.2	2.5	5.4	2.7
	1914							
3037	October	24.69	5	2.5	5	...	6	3
3038		24.71	5	2	5	3	6	2.5
3039		24.73	6	2	5	...	...	...
3077	December	31.60	4	...	6	2	6	3
3078		31.64	5	2.5	5	2	6	...
	1914, Oct.-Dec. MEAN		5.0	2.2	5.2	2.3	6.0	2.8

ations are spasmodic. As for the early evidence of change, Sherman's observation of a dark λ 5020 may easily have been an error of record or he may have observed an absorption border of this line. Further, in view of the relative faintness of these metallic emission lines and in view of the structure found in them, it seems reasonable that the apparent variations of λ 4584, observed by Sidgreaves, are ascribable to the uncertainties of photographic registration. That Miss Maury referred to λ 5023 and not to λ 4584 as one of the strongest of the emission lines in the spectrum of γ Cassiopeiæ, aside from those of hydrogen, is explained if we note that this observer did not identify λ 4584 as an emission line but did consider it erroneously as a bright region between two Orion lines. Apparently the probability of the reality of the suspected marked changes in the metallic emission lines in this spectrum is small.

There remains the possibility that changes may be taking place in the relative brightness of the two components into which the emission lines are divided by the central dark reversal. Such changes are described on a later page of this volume in connection with the bright line star, H. R. 985. Changes, possibly of this character, are well known phenomena of the spectrum of β Lyræ. The Ann Arbor spectrgrams of γ Cassiopeiæ have been examined with a view of bringing out such changes if they exist. To this end the intensity of each component of the emission lines of Hζ, Hϵ, Hδ, Hγ, λ 4584 and Hβ, referred to the neighboring continuous spectrum, has been estimated on each plate, when available. These individual estimates are not reproduced here. It is sufficient to say that they do not support any hypothesis of variation. The means by years and the final means for the set are found in Table IXa. Variations of the means for any component and of the relative brightness of two components of the same line from year to year are not too great to be accounted for entirely by uncertainties of estimation and of photographic registration. Apparently this type of variation is not present in the spectrum of γ Cassiopeiæ, so far as these direct relative estimates are concerned.

Line Structures. Several observers have pointed out that the hydrogen lines in the spec-

trum of γ Cassiopeiæ are in general doubly reversed. Narrow central absorption divides a wide emission line and this in turn is centrally superposed upon an extremely wide absorption background. The Ann Arbor spectrograms bring out the fact that this structure extends also to the other emission lines. In Table IV are found several measures of central absorption in metallic emission lines, and in Table X, measures of the absorption border of λ 4584.

The wide absorption borders on either side of the hydrogen emission lines are well known features of spectra of this class. In the case of β Lyræ a study of these borders has led the writer to conclude that they are made up of a group of narrow lines. In the case of γ Cassiopeiæ the same conclusion is suggested; and the less complex character of the hydrogen lines in this star has tended to facilitate the study of this line structure.

For all of the emission lines on all of the plates of Table VI the writer has measured the positions of the components of the absorption borders where settings were possible. At best these lines are difficult. Frequently they are blended, making identification uncertain. In general, when forming means, it is not possible to pick out the single lines from the blends. After some experiment the writer has adopted the expedient of plotting the frequency curves of the measures of such lines, using for abscissæ distances from the centers of the emission lines, and for ordinates the number of measures made within selected narrow limits. The positions of the maxima of such curves were assumed to correspond to the positions of components of the group, thus making possible the determination of the wave-lengths of these lines.

A frequency curve of this character for the Hδ line is shown in Plate I of this paper. The abscissæ represent distances from the center of the emission line in terms of micrometer turns. The ordinates are proportional to the number of lines measured on all plates between limits of five microns on either side of the plotted points.

The dispersion at the Hβ line was too small on these plates to permit of consistent resolution of the component lines in the absorption

TABLE IXA. INTENSITY OF EMISSION COMPONENTS RELATIVE TO THE CONTINUOUS SPECTRUM.

YEARS AND MONTHS	Hζ		Hϵ		Hδ		Hγ		Hβ		λ 4584	
	V	R	V	R	V	R	V	R	V	R	V	R
1911, July–Oct.	1.00	1.00	1.05	1.04	1.16	1.15	1.47	1.47	1.89	1.88	1.17	1.17
1912, Sept.–1913, Feb.	1.00	1.00	1.06	1.05	1.22	1.19	1.46	1.44	1.88	1.91	1.19	1.20
1913, Aug.–1914, Feb.	1.02	1.04	1.08	1.07	1.23	1.23	1.43	1.43	1.87	1.90	1.15	1.16
1914, Oct.–1916, Jan.	1.02	1.02	1.03	1.03	1.20	1.22	1.40	1.36	1.83	1.83	1.15	1.15
1911–1916	1.01	1.01	1.05	1.05	1.20	1.20	1.44	1.43	1.87	1.88	1.17	1.17

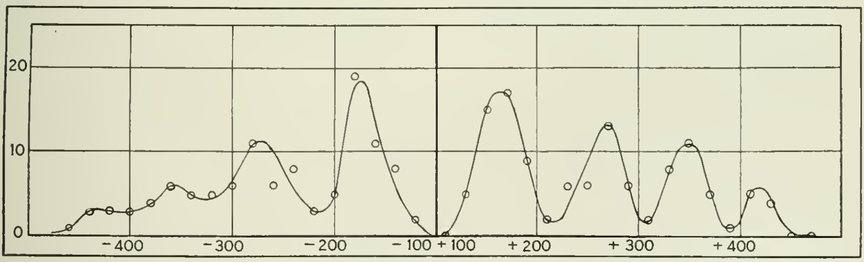

PLATE I. DISTRIBUTION CURVE OF MEASURES OF NARROW COMPONENTS OF ABSORPTION BORDERS OF Hδ

borders, measured at Hδ and Hγ. The relative weakness of the spectrum at Hε and the ill-defined appearance of this line have combined to interfere with measurements at this point. But frequency curves have been constructed for each of the lines in Table IX and from such curves the data of this table have been obtained. In this table, R and V with subscripts refer to components in the absorption borders on the side of the emission line to the red and to the violet respectively. The quantities in the body of the table are distances in angstroms from the center of emission lines to associated border components.

The average values of the distances of the inner components, V_1 and R_1, from the center of the corresponding emission lines are proportional to the wave-length of these lines within limits of one or two tenths of an angstrom. This is in agreement with the writer's conclusions in connection with these features in the spectrum of β Lyræ. The average distances of the components in the borders of the Hγ in β Lyræ, from the center of the associated emission line were 2.68, 3.94, 5.37, and 7.01 angstroms, beginning with the inner components. These distances for β Lyræ average only one or two tenths of an angstrom less than the corresponding quantities for γ Cassiopeiæ and the general resemblance between these quantities for these two stars is clearly suggestive.

TABLE X. DISTANCES OF BORDER COMPONENTS FROM CENTERS OF EMISSION LINES.

	Hε	Hδ	Hγ	λ4584	Hβ
R_4	.....	6.30Å	.....	.....	.....
R_3	.....	5.10	5.51Å	.....	.....
R_2	.....	4.05	4.28	.....	.....
R_1	2.26Å	2.47	2.91	3.42Å	3.54Å
V_1	.....	2.59	2.80	3.30	3.54
V_2	.....	4.10	4.44	.....	.....
V_3	.....	5.21	5.58	.....	.....
V_4	.....	6.33?	6.94	.....	.....

Width of Emission Lines. Measures of the separation of the parts of the reversed emission lines in γ Cassiopeiæ and other similar stars have been published by Merrill.[2] These measures are of especial value because the variation of this separation from line to line and from spectrum to spectrum is obviously dependent upon physical conditions in these stars. For the same reason it is evidently desirable also to have available measures of the actual width of the emission lines in these spectra if such measures can be made with an accuracy sufficient to bring out existing variations.

During his study of the spectrograms of γ Cassiopeiæ, the writer has measured the width of the emission lines observed in all cases where the edges of such lines seemed well defined. Frequently, and especially in the cases of Hδ and Hγ, there was a sharp density gradient at the edge of these lines, where the emission component suddenly gave way to the wide absorption border. It was on this narrow gradient that the writer set the micrometer thread in determining the position of the edge of the emission line. The results of these measures of the width in angstroms of the emission lines of Hδ, Hγ, and Hβ are given for each spectrogram in the last three columns of Table VI. The mean results for these and other lines are found in Tables XI, XII and XIII.

Before making any deductions from the measures of the widths of the emission lines it seemed advisable to determine to what extent, if any, the measures of these widths were affected by over- and under-exposure. Accordingly the plates were surveyed with this in view and the spectrum in the neighborhood of each measured emission line was designated according to density as very weak, weak, normal, strong and very strong, indicated in Table VI by the letters, W, w, n, s, S respectively. For each line all the measures in each density class were combined into means with results as tabulated in Table XI. From the data of this table it appears that only in the case of the Hβ line is there a clear dependence of the measured width of the line upon the density of the spectrum, and, as would be expected, the measured width increases with spectral density. In the visual region the Hα line exhibits this effect still more strongly, having a bright core with fainter edges which increase greatly the apparent width of

the line with lengthened exposure. But, allowing for the uncertainties affecting the results from these two lines, there appears to be much material in the present measures for comparative studies of the widths of the emission lines in the spectrum of γ Cassiopeiæ.

TABLE XI. AVERAGE WIDTHS OF EMISSION LINES GROUPED ACCORDING TO DENSITY.

DENSITY	WIDTH			
	Hδ	Hγ	λ 4584	Hβ
Very Weak	3.81Å	......	......	4.74Å
Weak	4.04	4.35Å	5.52Å	5.09
Normal	3.87	4.46	5.29	5.09
Strong	3.86	4.39	5.29	5.42
Very Strong	......	4.39	......	......

Comparing the measured widths in the last three columns of Table VI, for any line on different plates there seems to be no evidence of a real variation in this quantity. Discrepancies, very probably due to uncertainties of measurement, between measures of the width of the same line on plates made within a few minutes of each other are of the same order as the differences between results from plates of different nights, indicating that these differences may be attributed to accidental errors of measurement.

Referring to the mean values of Table XIII, it is obvious that the width of the emission lines increases with increasing wave-length. Merrill[2] has examined the separation of the two parts of the emission lines in ϕ Persei and has found that this "separation apparently varies linearly with the wave-length or a little more rapidly, though this is not borne out by the Hα line." To facilitate the determination of the relation between emission line widths and wave-length in the spectrum of γ Cassiopeiæ the plot of Plate II has been drawn with the former as ordinates and the latter as abscissæ. Apparently a linear relation is strongly suggested here. The equation of this line is $d\lambda = 0.001885\,(\lambda - 2020)$. Making reasonable allowance for increase in width of lines due to slit width and diffraction, the constant, 2020, becomes smaller and may approach zero.

Relative Position of Emission and Central Absorption. In the cases of a number of the Class B spectra with reversed emission lines the narrow absorption appears to be centrally superposed upon the associated bright component. But in several cases the division of the emission line is clearly not symmetrical. In every case it seems desirable that the relative positions of the centers of the emission component and of the reversal should be determined quantitatively in so far as the measurability of the lines will warrant. Such data may throw light upon circulation, pressure and temperature conditions, and particularly upon pressure and temperature gradients, in the atmosphere of stars having spectra of this kind.

TABLE XII. MEAN WIDTHS OF EMISSION LINES BY SEASONS.

YEARS AND MONTHS	WIDTHS OF EMISSION LINES									
	Hδ	NO. OF MEAS.	λ 4233	NO. OF MEAS.	Hγ	NO. OF MEAS.	λ 4584	MEAS. NO. OF	Hβ	NO. OF MEAS.
1911, July–October	3.96Å	17	4.48Å	3	4.30Å	25	5.23Å	7	5.10Å	26
1912, Sept.–1913, Feb.	4.01	13	4.18	3	4.43	22	5.34	11	5.04	23
1913, Aug.–1914, Feb.	3.80	12	3.73	4	4.46	19	5.32	5	5.04	21
1911–1914	3.94	42	4.09	10	4.40	66	5.30	23	5.06	70

Means of emission line widths by seasons are found in Table XII and the final means for all lines measured are given in Table XIII. Of variation from season to season there seems to be no evidence in Table XII.

On sixty-one of the seventy plates in Table VI, measures were made of the relative positions of the centers of the emission lines and of the

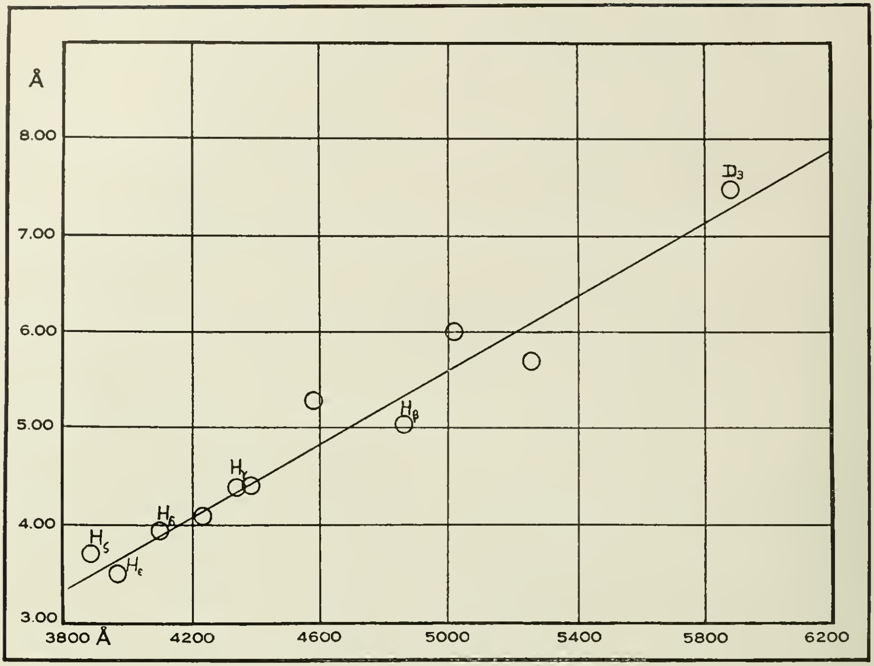

PLATE II. VARIATION OF WIDTH OF EMISSION LINES WITH WAVE-LENGTH.
EQUATION OF LINE, $\Delta\lambda = 0.001885\ (\lambda - 2020)$

TABLE XIII. FINAL MEANS OF MEASURES OF WIDTHS OF EMISSION LINES.

WAVE-LENGTHS	WIDTHS	MEAS.	REMARKS
3889	3.7−	1	$H\zeta$
3970	3.5−	4	$H\epsilon$
4102	3.94	42	$H\delta$
4233	4.09	10	Fe
4341	4.40	66	$H\gamma$
4384	4.42	5	Fe
4584	5.30	23	Fe
4862	5.06	70	$H\beta$
5018	6.0±	4	Fe
5260	5.7±	5	Group of three lines. λ's 5169, 5278, 5317.
5876	7.5±	1	D_3
6563	9.	2	Width of core. $H\alpha$

associated narrow reversals. The results expressed in kilometers per second for each plate are given with accompanying weights in columns 7 and 8 of Table VI in the sense, emission — absorption (E — A). Only the hydrogen lines, $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$ were used in these determinations and no measure was included unless both the emission and the absorption components were observed, thus eliminating errors due to assumption of wave-lengths. The values of E — A were combined into means for each plate since, as appears below, the mean values indicate that this quantity does not vary from line to line over limits that would be appreciable here. In measurements of the emission components of these lines settings were made on the edges and also upon the centers but in the reductions only the

latter were used. Indeed these bisections of wide emission lines yielded more consistent results than did the measures on the narrow reversals.

The velocities in column 7 of Table VI, representing the relative displacements of emission and absorption components (E — A), in the hydrogen lines of γ Cassiopeiæ, apparently do not vary more than would be expected of such quantities when determined from relatively few spectral features, not well defined. That the variations found in these quantities are accidental is supported by the fact that the differences between the quantities, E — A, for plates made at intervals of a few minutes on the same night are no less on the average than those for plates of different nights, the average variation of E — A between successive determinations on the same night being $\pm$ 9.4 km. and for different nights, $\pm$ 8.7 km.

The lack of probability of the existence of a periodic variation in the quantities, E — A, for the hydrogen lines of γ Cassiopeiæ is well brought out also by a study of the distribution curve of the observations of column 7 of Table VI, as compared with the probability curve according to the method proposed by Schlesinger.[26] The data for such a distribution curve are found in Table XIV where, in column two is given the number of velocities for the velocity interval in the first column.

The graphical representation of the material in Table XIV is made in Plate III. In this plot the abscissæ are velocities; the ordinates are numbers of plates. The probability curve shown in this figure corresponds to a probable error for a single determination of E — A of $\pm$ 5.0 km. and has a maximum ordinate at + 0.4 km. These values of the probable error of a single determination and of the maximum ordinate of the probability curve are in satisfactory accordance with values of these quantities found in other ways.

TABLE XIV. DISTRIBUTION BY VELOCITIES OF E — A.

VELOCITY INTERVAL		NUMBER OF OBSERVATIONS
km.	km.	
— 27 to	— 23	0
22	18	1
17	13	3
12	8	6
7	— 3	9
— 2	+ 2	19
+ 3	7	15
8	12	3
13	17	3
18	22	1
+ 23	+ 27	0

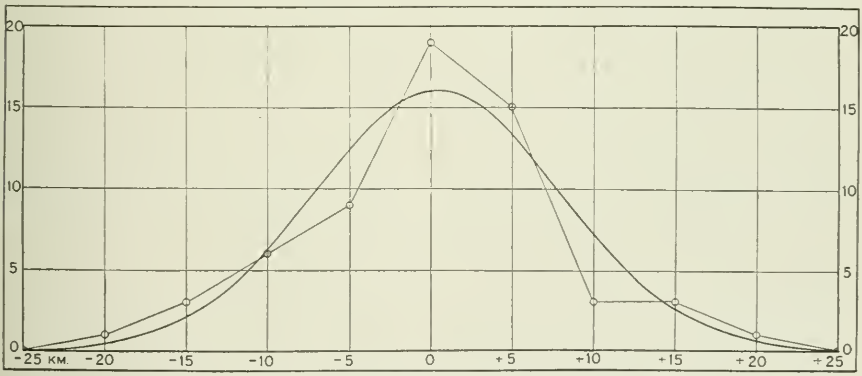

PLATE III. DISTRIBUTION CURVE OF DIFFERENCES BETWEEN EMISSION AND NARROW ABSORPTION LINE VELOCITIES COMPARED WITH ERROR CURVE

[26] *Astrophysical Journal*, Vol. 41, page 162.

Further, the plotted points in the figure follow the probability curve as closely as might be expected in a case of this kind. There is no clear indication that the quantity studied here is variable. If a variation exists it is probably small, or it may consist in a slow change in a period counted in years.

To test the possibility of a small slow change from year to year, or of a variation from line to line in the quantity, E — A, for γ Cassiopeiæ, means of this difference have been formed by years for each hydrogen line, in Table XV. These means with their probable errors are found in this table; and in the last two lines, means and probable errors, both in kilometers and angstroms, for the whole set of plates. It is interesting to note that these means for $H\epsilon$ and $H\gamma$ are persistently negative and for $H\delta$ positive, but such means are so nearly of the same order as their probable errors that there seems to be no reason to conclude that they indicate actual divergence from the mean for all the lines. Considering then the means for all lines by years the results in this table indicate within limits of a few hundredths of an angstrom that the quantity, E — A, for the hydrogen lines considered did not vary from year to year. The final means for all the measures show that it is probable that the quantity, E — A, did not differ from zero, for the hydrogen lines measured, by an amount exceeding a few hundredths of an angstrom, or, in other words, that the absorption reversals did not deviate, on the average, from the centers of the emission lines of hydrogen by quantities greater than this.

Radial Velocities. Seventy radial velocities of γ Cassiopeiæ, derived from spectrograms made on thirty-five different nights, are found in column three of Table VI. These velocities have been made to depend upon the emission and central absorption components of $H\delta$ and $H\gamma$ and upon the emission component of $H\beta$, since these features stand well above all others in this spectrum in point of measurability. This combination of emission and absorption components into means, which in general would not be wise, was justified by the indication, brought out above, that the absorption reversals occupy a fixed central position in the emission lines within limits that are negligibly narrow. As only the three lines mentioned were used here, the velocities in column three of Table VI and all the wave-lengths derived in this paper depend upon the following wave-lengths: 4101.92 Å for $H\delta$, 4340.63 Å for $H\gamma$, and 4861.53 Å for $H\beta$; and through the use of both their emission and absorption components the wave-lengths for $H\delta$ and $H\gamma$ have had a double influence on the results. The residuals for the velocities in column three of Table VI from a grand mean of -7.3 km. are found in column five and the corresponding number of lines measured with plate weights on the system used throughout this paper are found in the next two columns.

In view of the announcement by Hartmann and of the inclusion of γ Cassiopeiæ in lists of spectroscopic binaries, it is of interest to study the radial velocities of Table VI for indications bearing upon the question of variability. And apparently we may approach this investigation in several different ways. In the first place we may compare the differences between velocities from plates made at intervals of a few minutes on the same night with differences for successive

TABLE XV. RELATIVE DISPLACEMENTS; EMISSION MINUS ABSORPTION REVERSALS.

INTERVALS	DISPLACEMENTS; E — A				
	$H\epsilon$	$H\delta$	$H\gamma$	$H\beta$	MEANS
1911, July—Oct.	$-6.- \pm 10$ km.	$+1.1 \pm 1.6$ km.	-1.2 ± 1.2 km.	$+15.- \pm 5.-$ km.	$+0.32 \pm 1.0$ km.
1912, Sept.—1913, Feb.	$-2.- \pm 10$	$+2.9 \pm 2.1$	-1.8 ± 1.6	$+8.3 \pm 4.-$	$+0.77 \pm 1.2$
1913, Aug. 1914, Feb.	$-7.- \pm 7$	$+3.4 \pm 2.0$	-2.7 ± 1.6	$-3.4 \pm 4.-$	-0.44 ± 1.1
1911—1914	$-5.5 \pm 5.-$	$+2.3 \pm 1.0$	-1.8 ± 0.8	$+4.5 \pm 3.-$	$+0.24 \pm 0.63$
1911—1914	-0.072 Å	$+0.032$ Å	-0.026 Å	$+0.073$ Å	$+0.004 \pm 0.010$ Å

plates of different nights. Apparently, if the star's velocity is variable in a period of a few days or weeks, the latter differences should exceed the former on the average. In Table XVI these differences are compared for each season and for the entire series of plates. On the average the

TABLE XVI. VELOCITY DIFFERENCE FOR SUCCESSIVE PLATES.

YEARS	DIFFERENCES FOR SAME NIGHT	DIFFERENCES FOR DIFFERENT NIGHTS
1911	± 5.1 km.	± 7.2 km.
1912-1913	4.9	6.8
1913-1914	7.6	5.9
1911-1914	5.7	6.7

error of the average plate, determined from the internal line residuals, with the element of error known to arise normally from instrumental sources, systematic measurement errors, etc., thereby deriving a probable error for a single plate which should agree closely with values of this same quantity obtained from the residuals of column four of Table VI, unless the velocities of this table are variable. Following this procedure we find the probable error of the average plate of Table VI, determined from the internal line residuals, to be ± 3.0 km. Assuming that the uncertainties due to instrumental sources, systematic measurement errors, etc., average ± 1.0 km. we obtain a value of ± 3.1 km. for the probable error of a single average plate. From the residuals of Table VI we obtain a value of ± 3.3

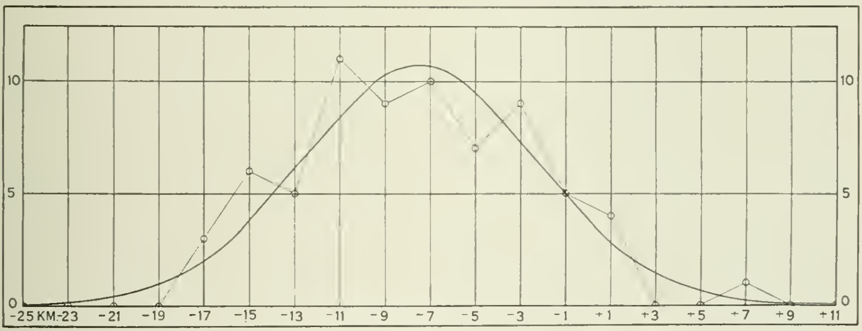

PLATE IV. COMPARISON OF DISTRIBUTION CURVE OF VELOCITIES OF γ CASSIOPEIAE WITH THE PROBABILITY CURVE

differences for different nights are slightly in excess of those for the same night but this excess is very probably due largely to accident, as the results for 1913-1914 seem to indicate, or possibly in part, to the constancy of instrumental errors for plates made in rapid succession. However, if we consider this difference real, it suggests a velocity variation of about five kilometers for γ Cassiopeiæ, if the period is measured in days or weeks. Apparently many observations would be required to establish the reality of such a variation.

Again we may examine the evidence of velocity variation for γ Cassiopeiæ on the basis of probable errors. Thus, we may combine the probable km. for this quantity. If we assume that this difference between 3.1 and 3.3 is due to variable velocity of γ Cassiopeiæ and if the velocities of Table VI be considered to be well distributed over a velocity curve not far from circular, the double amplitude of such a curve would be about four kilometers.

Again, to detect evidence of variation in the velocities of Table VI, we may compare their frequency or distribution curves with the probability curve in the manner employed above for the quantities, E — A. In the upper curve of Plate IV this is done for the individual velocities with ordinates corresponding to numbers of plates. The probability curve corresponds to a

TABLE XVII. RADIAL VELOCITIES OF GAMMA CASSIOPEIAE AVERAGED BY SEASONS.

EPOCHS	RADIAL VELOCITIES					
	Hδ EMISS.	Hδ ABS.	Hγ EMISS.	Hγ ABS.	Hβ EMISS.	MEAN
	km.	km.	km.	km.	km.	km.
1911, Sept.	− 10.6 ± 1.3	− 12.8 ± 1.8	− 5.5 ± 1.0	− 5.4 ± 1.4	− 7.5 ± 1.5	− 8.0 ± 0.57
1912, Dec.	− 7.0 ± 2.8	− 8.0 ± 1.6	− 9.2 ± 1.5	− 8.5 ± 1.6	− 9.4 ± 1.5	− 8.5 ± 0.74
1913, Nov.	− 2.6 ± 2.0	− 5.6 ± 2.0	− 4.0 ± 1.2	− 1.7 ± 1.7	− 8.7 ± 1.5	− 4.9 ± 0.84
1911 to 1914	− 7.2 ± 1.2	− 8.9 ± 1.0	− 6.3 ± 0.6	− 5.1 ± 0.9	− 8.5 ± 0.8	− 7.21 ± 0.40

probable error for a single average plate of ± 3.50 km., with maximum ordinate at — 7.3 km. In the curve of Plate V the plates are grouped by nights into normal places. The probability curve here corresponds to a probable error of ± 2.50 km. and the maximum ordinate is at — 7.5 km. There seems to be nothing in this comparison to indicate that the velocities of Table VI are variable in a short period.

There remains the possibility that there is a slow variation in the velocity of γ Cassiopeiæ in a period to be counted by years. To test this, the velocities of Table VI have been combined into means by seasons in Table XVII for each measured feature separately. E and A denote emission and absorption respectively and the probable errors in the last column are based on the final mean of — 7.2 km. and thus are larger than they would be if based on the means by years. The differences, E — A, which may be read from this table differ by unimportant amounts from similar differences derived above. These differences arise because all measures, whether both components are present or not, are included here. The velocities in this table do not establish any changes from line to line or from year to year but they do leave open the possibility of a slow variation with a period and amplitude similar in character to that apparently suspected by Hartmann. Apparently the observations now available are not sufficient to give γ Cassiopeiæ a place in catalogs of established spectroscopic binaries.

In addition to the radial velocities discussed above a number of determinations were made

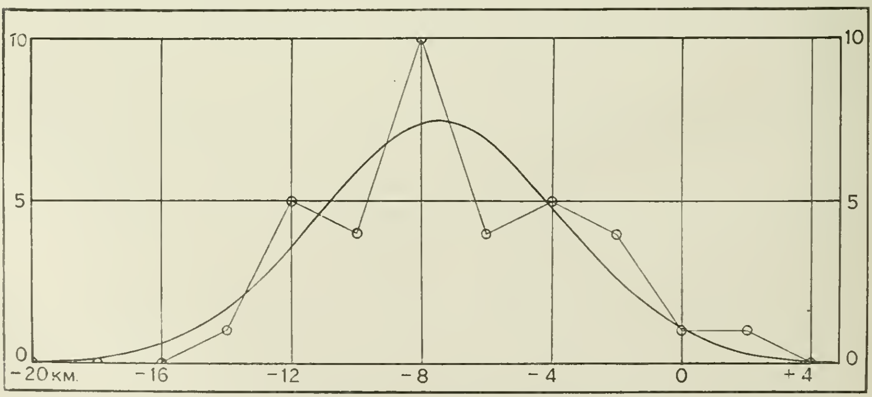

PLATE V. COMPARISON OF DISTRIBUTION CURVE OF VELOCITIES OF γ CASSIOPEIAE BY NIGHTS WITH THE PROBABILITY CURVE

from lines of very poor quality. Such results are based on the wave-lengths given in the last column of Table IV. They are assembled for the whole series of plates in the following table.

TABLE XVIII. RADIAL VELOCITIES DERIVED FROM INFERIOR LINES.

LINE	ELEMENT	COMPONENT	VELOCITY	PROB. ERROR	NO. OF MEASURES
K	Ca.	Absorption	−3.5 km.	± 2.0 km.	38
Hε	H.	Emission	+3.2	± 4.5	5
Hε	H.	Absorption	−1.1	± 2.8	29
λ 4045	He.	Absorption	+4.0	± 2.0	51
Hβ	H.	Absorption	−3.9	± 3.6	8

Combining all radial velocities of γ Cassiopeiæ measured at Ann Arbor into a final mean, with weights based upon probable errors, the result for the epoch of these observations (1912.8 ±) proves to be −6.4 ± 0.6 km. The inclusion of results from inferior lines may improve the final value through the use of more varied data but it actually increases the computed probable error of the mean. The final mean of the Ann Arbor velocities of γ Cassiopeiæ is compared below with the results of other observers.

	KM. PER SEC.
Vogel and Scheiner, 1888-9.	−3.5
Hartman, 1900-06,	−8.5
Campbell, 1896,	−2.6
Moore, 1903,	−2.8
Merrill, 1910-11,	−6.4
Merrill, 1912,	−2.6
Curtiss, 1912.8,	−6.4

SUMMARY

The foregoing paper is the second of a contemplated series of studies of bright line stellar spectra of Class B. The present report is devoted more particularly to a consideration of the spectrum and radial velocity of the star, γ Cassiopeiæ. The investigations of the present paper include: a study from several points of view of the sub-group of stellar spectra of Classes B to F, containing emission lines; a review of the published observations of the spectrum of γ Cassiopeiæ; a discussion of the evidence relating to the variability of features in this spectrum; a tabulation and review of published radial velocities and wave-lengths of this star; a study of the wave-lengths and intensity of the measurable lines between Hζ and Hα on seventy-five spectrograms of γ Cassiopeiæ made at the Detroit Observatory in the years, 1911 to 1914; quantitative studies of structures of the emission lines in these spectrograms; and determinations and critical discussion of radial velocities from seventy spectrograms of γ Cassiopeiæ made at this Observatory.

The principal deductions from a study of the sub-group of stellar spectra of Classes B to F, containing emission lines are:

1. These spectra, so far as known, tend strongly to group within the B division of the Draper Classification.

2. The apparent brightness of stars with these spectra is much greater on the average for Classes B0 to B5 than for Classes B8 to A2. Magnitude appears to become fainter on the average in stars of so-called greater effective age in this sub-group.

3. The strength referred to the neighboring continuous spectrum and number of the emission lines of hydrogren in these spectra are not clearly dependent upon spectral class, or, in other words, upon so-called effective age, so far as available data go.

4. From Merrill's study of thirty-eight of these spectra in Class B, it appears that the metallic emission lines tend to occur only in the early sub-divisions of this class or, in other words, under conditions thought to characterize stars in the earlier stages of development in this sub-group. And when these lines occur they are stronger on the average when the hydrogen emission is stronger.

The principal results of the published investigations of the spectrum of γ Cassiopeiæ by former observers are:

1. The spectrum of γ Cassiopeiæ is of Class B, with the hydrogen lines of the Huggins series from $H\zeta$ to $H\alpha$, each consisting of a wide emission line apparently superposed upon a very wide and diffuse absorption band. Except in the case of $H\alpha$ the wide emission line is centrally reversed. In addition to the presence of the hydrogen emission this spectrum differs from the norm of Class B in the occurrence of faint D_3 emission of helium and of many metallic emission lines, largely due to iron, and, probably without exception, found in the bright line spectrum of the solar chromosphere. The dark Orion lines in this spectrum are weak and ill-defined.

2. Visual observations have indicated that the emission lines, $H\beta$, D_3 and $H\alpha$ were strongly variable in intensity in the period, 1872-1888; the photographic record, which was obtained since that time, reveals no certain variation in these lines or in other emission lines.

3. The hydrogen emission lines decrease rapidly in intensity in succession toward the violet. At the same time the broad underlying dark band and the narrow dark reversal become more conspicuous, so far as observed, as the bright bands become fainter.

4. Tests of the $H\beta$ line have not revealed any certain polarization.

5. A variation in the radial velocity of γ Cassiopeiæ, announced by Hartmann, is not confirmed by observations made at Lick Observatory up to March, 1910.

The writer's deductions from his review of the published observations of the spectrum of γ Cassiopeiæ are:

1. Indications of uncertainty affecting visual observations and the constancy of the photographic record make doubtful the physical reality of the reported capricious changes during the era of visual observations (1872-1888) in the brightness of the emission lines of $H\beta$, D_3, and $H\alpha$. Evidence of variation in the metallic emission lines is not conclusive.

2. The success attending visual observations of D_3 emission in the interval from 1872 to 1888 indicates that this feature of the spectrum of γ Cassiopeiæ probably has been stronger, at least periodically, than at present.

3. The twenty-five radial velocities derived at Potsdam and the Lick Observatory support the conclusion that more observations would be necessary to establish the reality of Hartmann's announced variation.

The principal results of the study of the spectrograms of γ Cassiopeiæ made at Ann Arbor are as follows:

1. Determinations have been made of the wave-lengths and intensities of 112 features from $H\zeta$ to $H\alpha$ in this spectrum, with many suggested identifications.

2. It appears that the b group of magnesium is not certainly present in this spectrum.

3. Comparison of wave-lengths measured in this spectrum by Miss Maury, Sidgreaves, Baxandall, Merrill, and the writer, indicates similarity in characteristics at different epochs.

4. In the Ann Arbor spectrograms (1911-1914) there has been found no evidence of real variation from plate to plate or from year to year in the intensity of the emission lines of $H\delta$, $H\gamma$, $H\beta$, D_3 $H\alpha$ and of the metallic emission lines, nor in the central absorption of $H\epsilon$, $H\delta$, $H\gamma$, $H\beta$ and the metallic lines, nor in the dark λ 4026 and the K line. Estimates of the intensity relatively to the neighboring continuous spectrum of the two parts of the emission components of λ 4584 and the hydrogen lines, $H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$ and $H\beta$, furnish no clear indication of variation in the relative brightness of these features of the spectrum of γ Cassiopeiæ. The indication is that constancy was the rule in this spectrum during the period of these observations.

5. The metallic emission lines share the well known structure of the hydrogen lines.

6. The wide absorption borders of the emission lines are probably resolvable into narrow components. Narrow components of these absorption borders measured in this spectrum resemble those observed by the writer in the spectrum of β Lyræ, in point of distance from the center of the corresponding emission line.

7. Measures of the widths of the emission lines on the Ann Arbor plates of γ Cassiopeiæ indicate no real changes in these quantities from plate to plate nor from year to year.

8. A linear relation,

$$d\lambda = 0.001885 \ (\lambda - 2020),$$

between measured width and wave-length of all emission lines, is strongly suggested in the spectrum of γ Cassiopeiæ. On correction of measured line widths for slit width and diffraction, the constant, 2020, becomes smaller and may approach zero.

9. Determinations of the relative position of emission and central absorption of $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$ for sixty-one Ann Arbor spectrograms do not indicate any real variation in this quantity from line to line, from plate to plate, nor from year to year. If periodic variations exist they are probably small or so slow that observations covering many years would be required to reveal them.

10. The absorption reversals occupy the centers of the emission lines of hydrogen within limits of a few hundredths of an angstrom on the average and no certain deviation from this rule is found for individual lines.

11. Radial velocities determined from seventy spectrograms of thirty-five different nights in the years, 1911 to 1914, establish no variations from line to line, from plate to plate, nor from year to year.

12. A study of probable errors and a comparison of the distribution of the Ann Arbor observations with the probability curve indicate independently that there is no periodic variation in the radial velocity of γ Cassiopeiæ greater than a few kilometers in range unless the cycle covers many years.

13. The final radial velocity of γ Cassiopeiæ from all the Ann Arbor spectrograms is -6.4 ± 0.6 km., for the epoch, 1912.8. Combining all other known measures except those of Vogel and Scheiner, assigning equal weight to each determination, the radial velocity of this star is found to be -5.8 km. The final velocity based on all known measures is -6.2 km.

CONCLUSION.

With further studies in view of stellar spectra similar to that of γ Cassiopeiæ, an exhaustive discussion of the material now at hand might well be deferred. It remains to consider briefly, in connection with the results available, the theories which have been proposed to account for the peculiarities of γ Cassiopeiæ's spectrum and for the characteristics of the sub-group to which this star belongs.

In 1867, Huggins[5] inferred that the nearly uniform light of γ Cassiopeiæ suggested that the luminous hydrogen in this star forms a normal part of the photosphere. About twenty-three years later, with much more information on which to base a conclusion, Scheiner[27] proposed two explanations for the presence of bright lines in the spectra of stars like γ Cassiopeiæ: first, that they are produced by an atmosphere of hydrogen and helium at a higher temperature than the nucleus; second, that they are due to radiation from an atmosphere so extensive that the emissive spectrum of those portions of the atmosphere which project out beyond the star's real disk when superposed upon the absorption spectrum of the central parts overpowers it. The second explanation was offered by Scheiner as the more reasonable one and in this form is probably generally accepted today to account for the bright lines in stellar spectra of Classes B and A. In extension of this explanation Scheiner suggested that the width of the lines in these spectra was dependent upon the density of the atmosphere emitting them, and their structure upon its density gradients.

In 1894,[28] Scheiner had not accepted Campbell's observations of a bright $H\alpha$ coexistent with a dark $H\beta$ line. Apparently also he was not aware that the hydrogen lines beyond $H\zeta$, in the spectrum of γ Cassiopeiæ, are dark or neutral. Frost[29] and Kayser[30] pointed out that such a condition was not necessarily inconsistent with Kirchhoff's Law and Scheiner,[31] in 1908, accounted for it very simply on the basis of his own theory of an extensive atmosphere. It was necessary only to add the assumption that the hydrogen emission lines decrease in intensity toward the violet much as they do in the vacuum tube. Superposed on the corresponding absorption lines

[27] *Scheiner's Astronomical Spectroscopy.* Frost's Translation, page 250.

[28] *Ibid.*, page viii.

[29] *Astrophysical Journal*, Vol. 2, page 182.

[30] *Handbuch der Spectroscopie*, Vol. II, page 356. *Astrophysical Journal*, Vol. 14, page 313.

[31] *Populäre Astrophysik*, page 592.

produced by the atmosphere immediately in front of the nucleus, the visibility of the bright lines, beginning with the brightest, $H\alpha$, in comparison with the continuous spectrum, depends upon the extent and effective luminosity of the atmospheric projection, the strength of the neighboring continuous spectrum and the character of the background, for each line.

The hypothesis of an extensive atmosphere seems not inconsistent with the facts brought out above with reference to the spectrum of γ Cassiopeiæ. The constancy of the spectrum now observed and the variation suspected formerly in γ Cassiopeiæ and observed clearly in other stars such as Pleione and f^1 Cygni, seem not to negative this hypothesis in any way. The similar nature of the hydrogen and metallic emission lines suggests certain interesting conclusions with reference to the distribution of these substances. It might indicate that hydrogen and iron at least were well mixed in such an extensive atmosphere, and the fitting in of the widths of the metallic emission lines with those of the hydrogen lines would suggest an identical cause of widening. The symmetrical structure of the emission lines and the central position of the narrow absorption, considered as a reversal, should throw light upon the causes of broadening of spectral lines in an extensive atmosphere.

In connection with the very wide emission lines in γ Cassiopeiæ, conditions known to produce small effects are clearly of secondary importance. Such may be the Doppler effect of the component of velocity of the vibrating particle in the line of sight, changes of pressure, and possibly disturbances due to the presence of free electrons.

A source of apparent line broadening which may produce important effects in the supposedly extensive atmosphere of stars like γ Cassiopeiæ, is great thickness of the incandescent stratum of vapor. Scheiner[32] states that the spectroscopic equivalence of the density and thickness of such an incandescent gaseous stratum renders more difficult the formation of an opinion as to the constitution of a celestial object from the appearance of its spectrum and Zöllner expresses himself in similar vein. Kayser[33] and others point out that the width of a line is increased by the thickness of the radiating layer only when the intensity curve of such a line falls off gradually to the edge. It is a question then to how great an extent this factor has affected the lines in this spectrum. According to Scheiner the effect of increased thickness of the radiating stratum is to reduce the difference in brightness of two contiguous parts of the spectrum. The intensity curves of the emission lines in the spectrum of γ Cassiopeiæ seem not inconsistent with the hypothesis of an extensive atmosphere having the function of a radiating stratum.

Possibly the factor of greatest potency in increasing the width of single lines in stellar spectra is thought to be vapor density. In a star with a spectrum of Class B it is well known that the mean density is probably very low and that the greatest density of the radiating gaseous stratum may be less than that of the earth's atmosphere at sea level. However the combination of pressure and temperature, both probably high, may be competent to produce much of the widening of lines actually observed. But widening of lines through pressure is inseparably bound together with change of wave-length, and atmospheric pressure can hardly exist without pressure and density gradients. The narrow reversals of the emission lines of γ Cassiopeiæ indicate that such gradients exist, associated also with reasonable temperature gradients. It would be thought then that such reversals, produced under lower pressure conditions, would not occupy the center of these very wide emission lines even within limits determinable with a single-prism spectrograph. However balancing causes may be at work. Indeed the actual maximum of the emission lines from the lower stratum may be strongly displaced by pressure but such maxima differing in position for different layers might not form any well defined feature when combined in the integrated line and might be masked in any given star by several factors tending to smooth out the intensity curve of an emission line.

Among the factors tending to alter or smooth out the intensity curves of the emission lines in the spectrum of γ Cassiopeiæ great thickness of

[32] *Scheiner's Astronomical Spectroscopy.* Frost's Translation, page 130.

[33] *Handbuch der Spectroscopie*, pages 246, 296.

the emissive strata has been mentioned. A second possible factor is rotation. We do not know to how great an extent the atmosphere at various levels shares in the rotation of early stars nor how rapid such rotation may be, though in some cases it has been thought to be rapid enough to result in fission and the assumption of strongly ellipsoidal form. If the angular rotation of the atmosphere is as rapid as that of the nucleus, the center of the line corresponding to high levels will be broadened most thus tending to equalize the density of the line over its width and also, of course, the total width of the line may be increased. The relatively small width of the central absorption in the emission lines of γ Cassiopeiæ's spectrum may indicate that rotation does not play a very important role in the case of this star.

Atmospheric circulation, which, as the presence of iron vapor probably at high levels seems to indicate, may be rapid and far reaching in the case of γ Cassiopeiæ, could affect very appreciably the intensity curves of the emission lines in this spectrum. Probably the effects of the radial component of motion in such currents would be a widening of the lines and, since the ascending currents would be more highly emissive and more effective on the side of the star toward the observer, a displacement toward the violet. In the outer strata, producing the narrow absorption lines, such currents would probably not be so effective. Thus we might expect an apparent displacement of the emission line to the violet with reference to the reversal. This might balance or even overcome in some cases the opposite relative displacement due to pressure. In this way the central position of the narrow reversals in the emission lines of γ Cassiopeiæ may be accounted for even though the chief cause of widening is vapor density due to pressure, combined with high temperature.

The probability that the Zeeman or Stark effects are important among the factors affecting the intensity curves of emission lines in γ Cassiopeiæ seems small in view of the tests for polarization and separation made by Merrill.[2] And other suggested explanations such as the relative motion of two stars, may be dismissed without discussion. At present, Ekman's[40] resonance theory to account for the widening of spectral lines is developed hardly far enough for application here.

The approximately linear relation between emission line widths and wave-length, found in γ Cassiopeiæ, seems consistent with hypotheses of widening due to rotation and convection currents. Not enough is known about this relation for lines widened by vapor density or pressure to draw definite conclusions but it seems at least unexpected that the iron and hydrogen emission line widths in γ Cassiopeiæ, if they are due to vapor density and pressure combined with high temperature, should together bear any simple relation to wave-length. However, at least the fact of increase of width with wave-length for lines broadened by vapor density accords with theory and experiment.

It may be suggested that the possible role of electrical discharge must not be forgotten in connection with the light of these stars. In hot stars of low density, convection currents and other relative internal motions may produce great electrical disturbances with discharge which, especially in low pressure regions, may pass very freely. At least part of the light emitted by the atmosphere of γ Cassiopeiæ may be accounted for in this way. It is well known that the lines of a gas through which an electric spark is passing are broadened even under relatively low pressures. Possibly the emission lines in the spectrum of γ Cassiopeiæ have been broadened in this way. If so, a lack of appreciable displacement in them might not be unexpected.

Referring to the sub-group of stars to which γ Cassiopeiæ belongs Scheiner in *Die Spectralanalyse der Gestirne*[34] makes the statement: "There can be nothing more natural than to assume that the stars of Class Ic (exemplified by γ Cassiopeiæ and β Lyræ),[35] which have far more powerful atmospheres than those of Class Ia, are in a preliminary state from which they

[40] *Annalen der Physik*, Vol. 24, page 580.

[34] *Scheiner's Astronomical Spectroscopy*. Frost's Translation, page 250. See reference 27.

[35] Parentheses inserted. These stars are cited as types in Frost's translation of *Scheiner's Astronomical Spectroscopy*.

will pass over gradually into that of Class Ia (exemplified by Vega and Sirius).[35] They would therefore be considered as representing the earliest or 'youngest' phase of stellar evolution." Scheiner reiterates this view as a possibility in his *Populäre Astrophysik*,[36] and at least one other authority[37] has expressed agreement in the opinion expressed in the first sentence quoted.

On the other hand Miss Clerke[38] considered that the passage of dark line helium stars through a bright-line phase can be inferred to occur by exception in stellar history as a consequence perhaps of peculiarities of internal constitution, perhaps of unusual external influences.

Quite recently Doctor P. W. Merrill[39] has observed two bright line stars of Class A and Class A2 and has found that the characteristics of these two stars in the spectral region studied appear to be the same as those of bright line stars of Class B. Also nine spectra of Class Oe5 were photographed to test their relation to bright line spectra of Class B, since it is to be expected that bright Hα, at least, would be found in a considerable proportion of Class Oe5 spectra if they precede immediately in evolutionary order those of Class B and if the bright line spectra of the latter class are those of stars particularly early in development. But no bright lines were found. On the basis of the evidence at hand it was not possible to assign stars with bright line spectra of Class B to a place by themselves in evolutionary progression. Quite in accord with Miss Clerke's suppositions, Merrill suggests that it may be that special physical conditions, not uniquely connected with a particular epoch in effective age, give rise to bright hydrogen lines in stellar spectra of Classes B and A. Photographs at the Detroit Observatory of spectra of Class Oe5 confirm Merrill's result.

In support of the opinion that bright hydrogen lines are not uniquely connected with a particular epoch of stellar age we may add the statistical fact, brought out above, that the strength and number of emission lines of hydrogen in the spectra of the sub-group here discussed are not clearly dependent so far as known on so-called effective age. Possibly we may go farther and assert that the evidence indicates that stars with bright line spectra of Classes B to F form an evolutionary series running parallel with normal stars, differing only in some internal peculiarity—probably the possession of an abnormally extensive atmosphere.

Thus it seems difficult to agree with Scheiner in his opinion that the hydrogen bright line stars like γ Cassiopeiæ are the "youngest" stars. Too many spectra of this group are already developed into Class A. But the point may be raised that such spectra in Class A have never contained and will never show the dark Orion lines; that they are newly formed stars of which the atmospheres are so proportioned or constituted that the Orion lines are not evident. Further, the suggestion might be made that stars with spectra of Classes O and Oe5 and stars with bright line spectra in Classes B to F form two groups of "youngest" stars; the one evolved from the planetary nebula and the other from the irregular nebula. But the burden of opinion at present probably would favor the view that all stars develop in successive stages indicated by the spectral sequence, O, Oe5, B, A, and so forth, and that the occurrence of bright lines superposed on some of the absorption lines in many spectra of Classes B, A and F does not indicate for the stars emitting them a position in the evolutionary succession different from that of stars having similar spectra without *visible* emission lines.

A striking circumstance in connection with this group of stars is the strong tendency brought out above for average magnitude to become fainter with advancing spectral class. The indication would be that members of this group in Class O would average bright and that further discoveries of members of this group in Classes F and G may be expected when fainter stars are studied. Is it not probable that extensive atmospheres about these stars, or the lower layers of such extensive atmospheres, develop relatively strong general absorption, as compared with other stars of the same effective age, when Classes A and F are reached, thus making relatively faint this portion of the sub-group of bright line stars?

[36] *Populäre Astrophysik*, page 595.

[37] See reference 29.

[38] *Problems in Astrophysics*, page 279.

[39] *Lick Observatory Bulletins*, Vol. VII, page 23.

Another point is raised by the occurrence of strong hydrogen emission lines in Class A spectra. If stellar atmospheres are condensing and cooling as spectra develop from Class B to Class A, should we not find, for stars which give strong emission line spectra in Class A, forerunners with emission more intense than any so far observed? Apparently not, for it is the *relative* intensity of emission lines and neighboring continuous spectrum that determines the former's visibility, and on the average this relative intensity may remain the same while a spectrum develops from Class B to Class A, in a given case, even though the absolute brightness of these lines is much greater in Class B than in Class A. In some cases the emission lines are known to be fading relatively to the continuous spectrum. In other cases they may be found to be growing relatively stronger.

At many points in the above discussion attention is called again to the need of observations of spectra of Classes B, A, and F with bright lines, and of Classes O and Oe5. The program of observations at this Observatory has been extended to include spectra of Classes O and Oe5, and studies of bright line spectra of Classes A and F are contemplated.

Ann Arbor, Mich., December 3, 1915.

STUDIES OF CLASS B STELLAR SPECTRA CONTAINING EMISSION LINES

CHANGES IN THE SPECTRUM OF f[1] CYGNI

By RALPH H. CURTISS

In *Harvard Circular* No. 98, announcement was made of peculiarities in the Class B spectrum of f[1] Cygni (1900.0, $\alpha = 20$ h. 56.4 m., $\delta = +47° 9'$; mag. $= 4.9$). In an objective prism spectrogram of November 15, 1904, the hydrogen lines from Hζ to Hβ inclusive were found to consist of fine bright lines superposed on strong dark bands. In accordance with the well known rule of brightness of hydrogen emission in spectra of Class B, the intensity of these lines was found to diminish with diminishing wave-length. Other fine bright lines were visible.

Nine days later bright Hδ, Hγ and Hβ were photographed, the last two named lines being on the edge of shorter wave-length of the accompanying dark lines. The change observed between these two spectrograms seemed to indicate a binary character for this star, one component having bright hydrogen lines.

Since the emission of Hζ was visible on November 15, 1904, with an observed increase in the brightness of the other hydrogen lines with increasing wave-length it seems probable that the Hβ line and, in accordance with our knowledge of other stars, the Hα line must have been strongly bright. From the Harvard description it is difficult to determine whether the bright lines were reversed as in many of these stars or whether there was a single sharp emission component in each hydrogen band.

On a single-prism spectrogram of this star, of May 29, 1911, Doctor P. W. Merrill found Hγ probably bright in absorption and Hβ possibly bright in absorption, but the Seed 30 emulsion used was not effective in bringing out fine detail and small constrasts. On a spectrogram of June 6, 1912, with a single-prism instrument adjusted for visual light, the same investigator found Hβ and Hα indistinctly bright. He considered this spectrum to be peculiar and possibly variable. (*Lick Observatory Bulletins,* Volume VII, page 172.)

Twelve spectrograms of this star have been made with the single-prism spectrograph of this Observatory on Seed 23 plates. These are listed with the corresponding date of observation in the accompanying table.

In no case was emission observed in connection with the Hζ and Hϵ lines. These were always wide dark lines much like the lines of helium which are also present in this spectrum. Probably this is also true of the Hδ line though in some cases this line appeared asymmetrical, in one case in 1911 the presence of narrow emission on the side of greater wave-length was suspected, and in another case in that year the limits of an emission line may have been measured. But such emission line if it existed was not brighter than the neighboring continuous spectrum and was revealed only by the absorption of the underlying dark band.

The Hγ and Hβ lines on the seven plates of 1911, with the exceptions noted below, showed the structure which is characteristic of the hydrogen lines in many of the peculiar spectra of Class B. An emission line, divided by a dark reversal into two components, was superposed on an absorption band so wide that dark borders flanked the emission on either side. The reversal in this case was so wide that the components of the emission line were relatively narrow. Further the reversal was observed to be displaced toward the violet relatively to the center of the emission line in all but one case where measures could be made. Thus the emission component of shorter wave-length was narrower than the other. Also observations indicated that this sharper component of shorter wave-length tended to be the stronger.

The emission of Hβ averaged slightly brighter than the neighboring continuous spectrum in 1911, while the emission of Hγ was very nearly of the same intensity as the continuous spectrum in the Hγ region. Indeed without the evidence

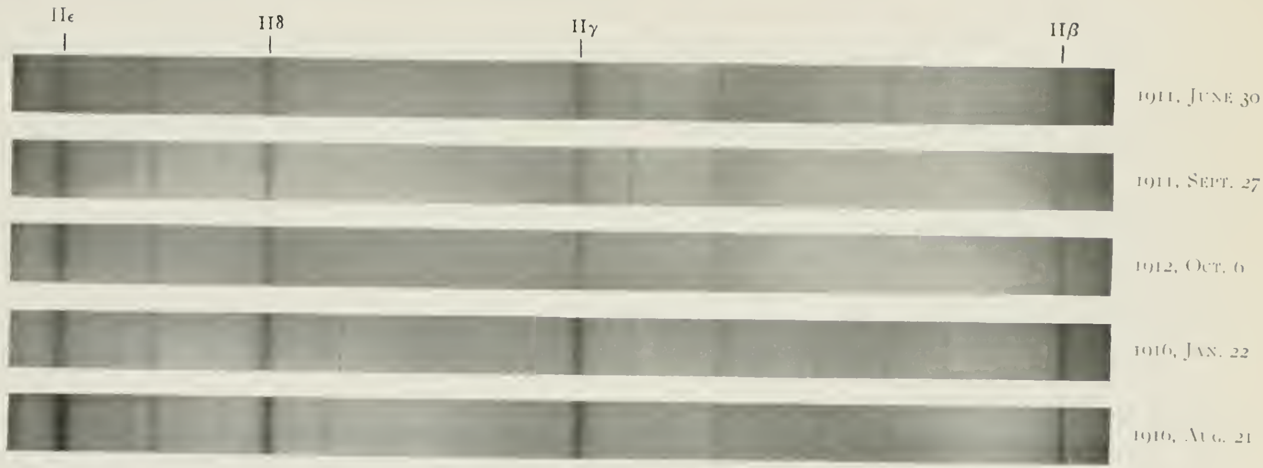

Plate D. Spectra of f^1 Cygni Showing Progressive Changes in Hε, Hδ, Hγ and Hβ, from 1911 to 1916

THE ANN ARBOR OBSERVATIONS OF f[1] CYGNI.

PLATE NO.	DATE G. M. T.	VELOCITIES REVERSAL	WT.	E — A	INTENSITY OF CENTRAL ABSORPTION Hδ	Hγ	Hβ	WIDTH OF EMISSION Hγ	Hβ
	d	km.		km.				A	A
69	1911 June 30.807	+33	2½	+33	10	10	9	7.20	9.80
74	July 1.797	+33	2½	....	11	10	9	....	....
87	5.803	+37	2½	+45	11	12	9	....	8.71
	Second measure	+38	3		11	10	9	....	....
114	July 11.871	+36	2½	+29	14	10	9	7.50	9.24
150	26.772	+33	2½	+17	14	12	12	7.69	10.36
162	30.772	+27	2½	— 5	12	11	10	....	8.71
227	Sept. 27.694	— 7	2½	+26	..	..	..	7.54	9.80
	Second measure	+ 1	3	+28	11	10	11	7.54	8.97
1197	1912 Oct. 6.673	— 9	3	....	15	12	12	....	....
3407	1915 Dec. 9.414	— 6	1	....	24	15	15	....	9.71
3416	14.588	—23	1½	....	25	16	16	....	....
3420	1916 Jan. 6.583	—24	1½	....	..	..	16	....	....
3427	22.568	— 9	2½	....	25	18	18	....	....
	MEANS			+25				7.48	9.33

of the absorption borders on either side and the better definition of the edges of the reversal, the existence of emission at Hγ would hardly have been suspected. Adopting Miss Maury's expressive term, the line was neutral.

The absorption border of shorter wave-length was stronger and was resolved in some cases into narrow dark lines. On six of the seven spectrograms of 1911 the absorption border was visible on the edge of shorter wave-length of Hγ and on four of these spectrograms it was visible on the edge of greater wave-length. The absorption border of shorter wave-length at Hβ was visible on all plates of 1911 and that of greater wave-length on all except plate 74. The invisibility of the absorption borders of Hγ and Hβ in five cases out of twenty-four, in 1911, seems ascribable to lack of suitable photographic contrast rather than to variation during this season. There was no plate showing less than two of these absorption borders of Hγ and Hβ.

On the plate of 1912, and on those of 1915 to 1916, the structure of the Hγ and Hβ lines appeared to be changed. The absorption borders were weaker or absent; the reversals, wider and less well defined. On plate 3420, which was sensitized according to Wallace's formula, underexposed continuous spectrum was faintly visible in the Hα region but no trace of emission was identified. Apparently at present there remain in the spectrum of f[1] Cygni only very uncertain and possibly vanishing traces of the structure, characteristic of emission lines in Class B spectra, which was probably pronounced in 1904 and was clearly shown in 1911. The Ann Arbor observations indicate the existence of a progressive change but the possibility of a short period variation, which was suggested at Harvard, is not excluded.

The velocities determined from the central absorption of the hydrogen lines Hδ, Hγ and Hβ are found in column three of the accompanying table. They appear to vary slowly, though over a wide range, toward smaller values. Whether this change is due to varying radial velocity or to alterations in the structure of the lines due to internal changes in the star can not be decided. The Hδ line, which showed no certain emission, and the helium lines so far as they can be measured, indicated the same velocity variation, but in these cases also internal changes in the star may be responsible for the measured

variations. If the variation is one of velocity the orbital period may be long, though a short period is not excluded.

In column four the excess of the velocity for the emission lines over that for the reversal is tabulated, where measured. The mean relative displacement amounts to 0.36 Å at $H\gamma$.

In columns five, six and seven the average increase from 1911 to 1916 in the intensities of the central absorption of $H\delta$, $H\gamma$ and $H\beta$ is brought out.

Columns eight and nine give the width of the emission lines of $H\gamma$ and $H\beta$, corrected for width of slit by the formula, $\triangle\lambda = 0.040\, d\lambda/dR$. If we assume a linear relation between line width and wave-length in this case, we arrive at the equation,

$$\triangle\lambda = 0.00356 \ (\lambda - 2240).$$

CONCLUSION.

From the descriptive and numerical data given above it seems apparent that there have taken place in the spectrum of f^1 Cygni changes involving the fading of the hydrogen emission lines, the effacement of the structure of these lines, an increase in the intensity of the narrower dark lines of hydrogen and a variation in their wave-length. There is evidence that this change is a progressive one.

Ann Arbor, Mich., Jan. 20, 1916.

STUDIES OF CLASS B STELLAR SPECTRA CONTAINING EMISSION LINES

CHANGES IN THE SPECTRUM OF H. R. 985

By RALPH H. CURTISS

The spectrum of the star, H. R. 985 or B. D. + 65 340, (1900.0, $\alpha = 3h\ 11.2m$; $\delta = +65\ 17'$; B. D. mag., 4.5; Harvard photographic mag. 4.86) in Camelopardalis was suspected of peculiarities by Espin on September 22, 1895. The total light was pronounced white; the type of spectrum was not determined but the F line of hydrogen was recorded as possibly bright. In *Harvard Annals*, Volume 56, Epsin is credited with the discovery of the peculiarity of this spectrum.

Previous to this observation by Espin, bright Hα had been observed in this spectrum by Campbell, and the photographic spectrum had been studied on sixteen objective prism plates at Harvard by Miss Maury whose detailed description, written several years at least before 1897, is found on page 105 of Volume 28 of the *Harvard College Observatory Annals*. With a note now inserted in parenthesis this description reads as follows:

"The system of dark lines in the spectrum of this star belongs to Group IV, Division b, but all the lines are exceedingly wide. (This last remark is not true of the H and K lines nor of the hydrogen reversals.) A distinct bright band lies almost centrally on the wide dark band Hβ. A fainter and narrower bright band or line lies upon Hγ, its position being commonly of slightly greater wave-length than the center. The lines Hϵ and Hδ appear in most photographs unequally divided, with the strong component occupying the true central position for each hydrogen line, and the weak and hazy component having the greater wave-length. In some plates, however, both these lines and Hγ appear triple. Other lines of the spectrum sometimes appear unequally divided, with the stronger component of shorter wave-length."

In Volume 56 of the *Harvard College Observatory Annals* this spectrum is classified as B2p, and the lines Hγ, Hβ and Hα are noted as bright.

In the *Lick Observatory Bulletins*, Volume VII, page 167, Doctor P. W. Merrill reports the salient features found on four spectrograms of this star made between July 28 and August 13, 1912, with single-prism spectrographs. Hα was a strong bright line; Hβ and Hγ were "double bright on absorption"; Hδ was probably "faint bright on absorption". Strong helium absorption was observed and traces of a few metallic emission lines were seen.

The twenty spectrograms made at the Detroit Observatory are grouped in two epochs—the first group of nine plates extending from October 26 to December 16, 1912, the second from January 22 to April 17, 1916.

On the plates of each of these groups the characteristics of the lines appeared to be essentially constant. A central reversal divided each hydrogen emission line into two parts and the edges of a broad underlying absorption band were visible on either side of the emission line. This structure was brought out very clearly in the case of Hβ, less clearly in Hγ, rather indistinctly in Hδ and quite indistinctly in Hϵ and Hζ. As in other stars of this sub-group the emission components decreased and the central absorption increased in intensity from Hβ to Hζ. Broad helium dark lines, too diffuse for useful velocity determinations, but sometimes giving evidence of the structure characteristic of the hydrogen lines, were observed at λ's 4009, 4026, 4121, 4144, 4388, 4472, and 4922. Metallic emission lines showing faintly the structure characteristic of the hydrogen lines were measured at λ's 4233, 4584, 4925 and 5018. In addition a narrow dark K line, probably fixed in position, was observed on many plates of both groups.

But in the interval between the two series of plates a striking change had taken place in the intensities of the two parts on either side of the central reversal of the emission bands of hydro-

gen. Briefly, in the first series of plates the part of the emission component having greater wave-length, so far as observed in the hydrogen lines, was stronger than that of smaller wave-length in nearly every case, whereas in the second series the reverse was the case. In Table I, the extent of this change for the different hydrogen lines is brought out. The table gives the estimated intensities of the parts of each hydrogen emission line referred to the neighboring continuous spectrum for each plate, the serial number of which is given in column 1, the date in Table II. R at the head of a column denotes the part of the emission component of greater wave-length; V the corresponding part of smaller wave-length.

Variations in the estimates of line intensities from plate to plate in the 1912 series, as well as in the 1916 series, are present and appear to be due to the well known uncertainties of photographic contrast, and partly perhaps in the case of Hϵ to the neighboring H line. It is not thought that they establish any variation within either series. Very probably the means for 1912 and for 1916 in this table represent quite well the relative intensities of the two parts of the hydrogen emission lines, as well as their intensities referred to the continuous spectrum at these epochs. Thus the part of greater wave-length of the Hβ emission component lost one-third of its strength between 1912 and 1916 while at the same time the part of smaller wave-length gained a similar amount in brightness; and the other hydrogen lines observed in the photographic region exhibited similar changes which, however, were less striking, largely perhaps because these lines were relatively fainter than Hβ.

The edges of the hydrogen emission lines were best defined when associated with strong emission components. And this was true also of the absorption borders of the emission lines. In

TABLE I. BRIGHTNESS OF PARTS OF EMISSION COMPONENTS REFERRED TO THE CONTINUOUS SPECTRUM.

PLATES	Hζ		Hϵ		Hδ		Hγ		Hβ	
	V	R	V	R	V	R	V	R	V	R
1360	0.6	0.8	0.6	0.8	0.6	0.9	...	...	1.3	1.6
1404	0.6	0.8	...	...	0.6	0.9	1.0	1.1	1.3	1.6
1449	0.4	0.8	0.7	0.7	0.6	0.8	0.9	1.1	1.2	1.5
1477	...	...	0.4	0.6	0.4	0.5	0.9	1.2	1.0	1.5
1504	...	...	...	...	0.4	0.9	0.9	1.1	1.3	1.5
1509	...	...	...	...	0.7	0.9	1.0	1.1	1.0	1.4
1532	...	...	...	...	...	...	...	...	1.0	1.4
1539	...	...	...	...	0.4	0.5	0.9	1.0	1.2	1.5
1554	...	...	0.4	0.6	0.6	0.8	0.9	1.1	1.2	1.4
MEAN 1912	0.5	0.8	0.5	0.7	0.5	0.8	0.9	1.1	1.2	1.5
3429	...	...	0.8	0.6	0.8	0.6	1.3	0.9	1.6	1.0
3430	...	...	0.7	0.4	0.7	0.4	1.2	0.8	1.5	0.9
3436	...	...	0.6	0.3	0.7	0.4	1.0	0.8	1.5	1.1
3437	...	...	0.7	0.5	0.8	0.5	1.1	0.8	1.5	1.1
3450	...	...	0.5	0.6	0.8	0.5	1.1	0.8	1.6	1.0
3454	...	...	...	...	0.5	0.5	1.2	0.9	1.6	1.0
3461	...	...	...	...	0.9	0.5	1.1	0.8	1.5	1.1
3463	0.6	0.4	0.7	0.4	0.7	0.6	1.2	0.8	1.4	1.1
3470	0.6	0.4	0.5	0.8	0.7	0.7	1.1	0.8	1.5	1.0
3471	...	...	0.6	0.8	0.8	0.5	1.0	0.8	1.5	1.1
3494	...	...	0.8	0.8	0.9	0.8	1.0	0.8	1.5	1.0
MEANS 1916	0.6	0.4	0.7	0.6	0.8	0.5	1.1	0.8	1.5	1.0

plates of the second group the edge of greater wave-length with its absorption border, even in the case of Hβ, was frequently difficult to observe.

Hα was observed as a strong emission line on one plate (Number 3430) of the second group; the only plate of the set sensitized to red light. On the scale used in column 24 of Table II, the intensity of this line would be about twenty. It was accompanied by strong absorption borders and no reversal was visible. Its width corrected for the width of the slit was about 5.5Å, but in view of the structure of the Hβ line it is possible that this measurement of width applies to only part of the normal Hα emission band. No other lines were noted clearly in the visual region.

In Table II, are given essentially complete data from twenty spectrograms relative to radial velocities, line intensities and line widths in the photographic region of the spectrum of this star. In this table in the column of dates the numbers before the decimal point refer to the day of the year. The abbreviation, Abs., refers to the central dark reversal of the hydrogen lines; I, to the intensity of lines on the scale used by the writer in his study of γ Cassiopeiae; p, to the weight of the observed velocities; E — A, to the differences between results for the broad emission components and the dark reversals of the same line. With these explanations the contents of the table will be readily understood.

For a case of this kind in which changes in the structure of the lines are observed and in which therefore more than the usual caution must be exercised in the interpretation of observed displacements as Doppler effects, it is unsafe to derive mean velocities without investigating first the behavior of individual lines. Accordingly in Table II the data for each measurable line are listed. Considering the velocities for any line in either the 1912 or the 1916 series the variations from plate to plate are not greater than we would expect for lines of this character if the velocity were not changing. In the first series it seems possible from the means for each line that the measured velocities tend toward algebraically smaller values with increasing wave-length, whereas in the second series the reverse seems to be suggested. However this indication is not strong enough to detract seriously from the value of plate means based on all the hydrogen lines. Furthermore since the velocities in columns 19 and 28 of Table II do not indicate any departure of the absorption reversals from the centers of the emission lines it appears allowable to combine velocities from emission lines with those from absorption lines in the plate means. Such plate means are found in column 29 of Table II. Possibly there is a slight progressive tendency toward algebraically greater values in the plate velocities through the series for 1912 but the divergence is small at most from the average of —3.1 km. for the series. No variation is suggested in the plate velocities of the 1916 series but the final average of + 41.9 km. differs forty-five kilometers from the 1912 average, a variation extending apparently to all the hydrogen lines so far as the measures give evidence and suggesting unmistakably a Doppler shift of the whole spectrum between 1912 and 1916.

As noted above it is necessary to proceed cautiously with the interpretation of shifts in this spectrum as Doppler effects. Displacements both apparent and real may be associated with the changes in structure of the hydrogen lines. Thus apparent displacement of the dark reversals might be expected to result from the observed changes in the relative intensity of the two parts of the emission lines which border the reversals. The somewhat large displacement of the Hβ absorption component as compared with the displacement of the other lines, between the 1912 and the 1916 series, may be due to this effect. But if this effect is important here we should expect the emission lines to show displacement in the opposite direction between the two series whereas there seems to be little or no evidence of this in the case of Hβ and none in Hγ. In the case of Hβ it is conceivable that the greater variation in the position of the central reversal between the 1912 and 1916 series, as compared with that of the emission component, is attributable to this cause. Probably in the plate means the extent of this effect does not exceed a few kilometers.

The K line of calcium on the plates of both series is narrow, having an intensity between

TABLE II. VELOCITIES, LINE INTENSITIES, AND LINE WIDTHS. H. R. 985.

PLATE NO.	DATE G. M. T.	Hζ			Hε			Hδ			Hγ								Hβ									PLATE MEANS		K-LINE	
		ABS.			ABS.			ABS.			ABS.			EMISSION				E–A	ABS.			EMISSION					E–A				
		VEL.	I	P	VEL.	I	P	VEL.	I	P	VEL.	I	P	VEL.	P	WIDTH	P	VEL.	VEL.	I	P	VEL.	I	P	WIDTH	P	VEL.	VEL.	P	VEL.	P
	1912	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	d	km.			km.			km.			km.			km.		Å		km.	km.			km.			Å		km.	km.		km.	
1360	300.757	+23	4	1	— 1	4	2	— 2	3	2	— 1	3	2	....	..	....	..	....	—37	2	4	—19	18	4	7.13	4	+18	—14	15	+23	1
1404	308.745	....	.	.	....	..	..	+23	4	2	—11	3	2	— 1	2	5.34	2	+10	—28	2	2	—17	16	2	6.66	2	+11	— 7	10	+ 4	1
1449	315.774	....	.	.	—11	4	2	+ 2	3	2	+ 4	4	2	+16	1	4.83	1	+12	— 5	2	4	— 1	16	4	6.81	2	+ 4	— 1	15	—11	3
1477	324.715	....	.	.	....	..	..	— 9	4	2	+ 6	3	4	— 6	1	5.78	1	—12	+ 1	2	4	— 8	15	2	6.75	2	— 9	— 1	13	+12	3
1504	327.777	....	.	.	....	..	..	+11	3	1	+ 5	3	2	— 7	1	5.40	1	—14	— 9	2	2	— 2	16	3	6.42	2	+ 7	— 1	9	+ 3	2
1509	332.677	....	.	.	....	..	..	—15	3	1	+13	2	1	+27	1	4.83	1	+14	—26	1	1	....	15	..	....	..	....	± 0	4	....	..
1532	335.657	....	.	.	....	..	..	— 3	4	1	....	..	..	....	..	....	..	....	....	..	..	+ 3	14	1	6.75	1	....	± 0	2	—27	1
1539	339.701	....	.	.	+11	4	2	— 7	3	1	— 4	2	2	....	..	....	..	....	—19	2	3	—17	15	2	6.39	1	+ 2	— 8	10	....	..
1554	349.635	....	.	.	....	..	..	+ 6	4	2	+22	3	4	+17	2	5.04	1	— 5	— 2	2	2	— 2	15	2	6.36	2	+ 0	+10	12	— 8	1
MEANS 1912		+23	4	1	± 0	4	6	+ 2	3.4	14	+ 6	2.9	19	+ 8	8	5.22	7	± 0	—15	1.9	22	— 9	16	20	6.58	16	+ 6	—3.1	..	— 6	12
	1916																														
3429	22.672	+31	8	2	+36	4	4	+45	4	4	+34	3	4	....	..	....	..	....	+61	2	3	+61	15	3	6.90	2	± 0	+44	20	— 5	2
3430	22.730	+19	4	1	+28	3	1	+29	3	2	+45	2	4	....	..	....	..	....	+51	1	4	+47	14	2	6.81	2	— 4	+42	14	— 9	1
3436	60.604	....	.	.	....	..	..	+21	4	1	+59	3	1	+58	1	....	..	— 1	....	..	..	+49	14	2	7.10	2	....	+47	5	—19	4
3437	60.633	+26	5	2	+64	4	2	+30	4	2	+48	2	2	+66	1	5.53	1	+18	+20	2	2	+26	14	2	6.48	2	+ 6	+38	13	—20	3
3450	75.605	....	.	.	+41	6	1	+19	4	2	+36	4	2	....	..	....	..	....	+43	2	2	+43	14	1	6.28	1	± 0	+35	8	—14	1
3454	76.637	....	.	.	+51	9	1	+58	5	2	+34	4	4	+38	1	5.42	1	+ 4	+56	2	2	+54	15	2	7.10	2	— 2	+47	12	— 8	2
3461	83.618	....	.	.	....	..	..	+35	5	2	+54	3	3	+46	1	5.32	1	— 8	+57	2	4	+39	14	2	6.45	1	—18	+49	12	—14	4
3463	90.635	+22	5	0	+38	5	1	+37	4	2	+36	3	3	....	..	....	..	....	....	..	..	+33	15	3	6.48	2	....	+35	9	— 1	2
3470	97.582	+53	5	1	+51	4	1	+49	3	2	+29	3	2	+33	1	6.25	1	+ 4	+43	2	2	+45	15	2	6.90	2	+ 2	+43	11	— 1	2
3471	97.616	+37	8	0	+56	2	2	+31	3	2	+36	3	3	....	..	....	..	....	+35	2	2	+41	15	2	6.28	2	+ 6	+39	11	— 8	2
3494	108.598	+43	5	1	+54	4	1	+32	5	2	+36	3	2	+29	1	5.05	1	— 7	+42	2	2	....	14	..	....	..	....	+38	9	—12	2
MEANS 1916		+33	6	7	+46	4.6	14	+37	4.0	23	+40	3.0	30	+45	6	5.51	5	+ 2	+48	1.9	23	+44	14	21	6.71	18	— 1	+41.9	..	—11	25

NOTE.—The spectrograms of this table were made on Seed 23 plates except numbers 1509 and 1532 for which Seed 30 plates were used. The normal exposure for this spectrum on a Seed 23 plate was about thirty minutes. Plates 1504, 1509, 1539, 3436, 3437, 3450 and 3494 were made by Mr. Mellor; plate 1477 by Messrs. Hess and Crump. The other twelve spectrograms were made by the writer.

two and three, but as a rule is not well defined. The velocities derived from this line in the 1912 series do not indicate variation nor divergence from the values derived from the hydrogen lines. The velocities from the K line in the 1916 series do not indicate internal variation but they differ markedly from the corresponding results for hydrogen. Probably the K line is fixed in position in the spectrum of this star and is displaced from its zero position by an amount corresponding to — 9 km. per second of velocity.

In addition to the results in Table II velocities were derived from measures of the broad helium lines. But such velocities were not reliable enough to determine whether these spectral features shared the displacements of the hydrogen lines.

Two measures of the emission component of Hδ gave results in accord with velocities derived from the corresponding reversals.

The line intensities in Table II do not establish any changes in the strength of the absorption reversals nor in the total intensity of the Hβ emission line. The latter observation is in accord with the quantities in Table I.

Measures of the positions of the emission components of Hγ and Hβ for the determination of velocity were made both by bisecting the entire line and by setting on its edges. The latter measures furnished the determinations of the width of the emission components of Hγ and Hβ in columns seventeen and twenty-six of Table II. Since the emission component of the Hγ line averaged no stronger than the neighboring continuous spectrum, and since one-half of the Hβ emission was always relatively weak, the measures presented some difficulty. They cannot be said to establish any changes in the widths of these lines.

The mean widths of the Hγ and Hβ emission components are 5.34Å and 6.65Å respectively. The width of the nearly monochromatic comparison lines in this region is 20 microns. If this be converted into angstroms and subtracted from the measured widths of emission components the results above become 4.58Å and 5.47Å respectively. If we assume a linear relation between wave-length and line width, as suggested by studies of ϕ Persei and γ Cassiopeiae, the equation of such a line becomes

$$\triangle \lambda = 0.00170 (\lambda - 1640).$$

SUMMARY

The bright line Class B spectrum of H. R. 985, though showing in the hydrogen lines the structure typical of such spectral features in objects of this sub-group, is of unusual interest because of marked changes observed between the years 1912 and 1916, in the relative intensities of the two parts into which the emission components of hydrogen were divided by the narrow central absorption. At the same time no certain changes in the *total* intensities of the lines in this spectrum were thought to be registered, and *within* the series of plates in 1912, October to December, and in 1916, January to April, no changes in the relative intensities of a given part of any emission line were found to be established.

The hydrogen lines showed as a whole a relative displacement of forty-five kilometers between 1912 and 1916 on the assumption, probably well justified, that such displacement was common to all of them; but within the series in 1912 and within that of 1916 no change in the measured velocities was established, though the possibility of some change during the 1912 series is suggested. The mean velocity for the 1912 series was — 3.1 km. and for the 1916 series, + 41.7 km.

The K line was narrow and apparently fixed in position throughout the whole series of plates. The mean velocity derived from it was — 9 km.

Though wide lines of helium and several metallic emission lines were present in this spectrum no features in the photographic region other than the hydrogen lines were available for velocity determinations.

The widths of the emission components of Hγ and Hβ were not found to be certainly variable and were found to be in the mean 4.58Å and 5.47Å respectively.

CONCLUSION

Probably the most plausible conclusion suggested by the above observations of the spectrum of the star, H. R. 985, is that at least two bodies

are involved, forming a system with a long orbital period—possibly about 2.3 years. The radial velocity variation may be attributed to orbital motion but on this basis the explanation of the probably simultaneous changes in the emission lines is not obvious, though it must appear reasonable that the two variations are related.

Apparently the variations which the Ann Arbor observations have brought out in the spectrum of this star account for Miss Maury's puzzling description quoted above of the Harvard objective prism plates of H. R. 985.

Evidently this star must be observed over a relatively long time interval, even though the variable phenomena prove to be periodic, before the story of its spectral variations can be written.

April 24, 1916.

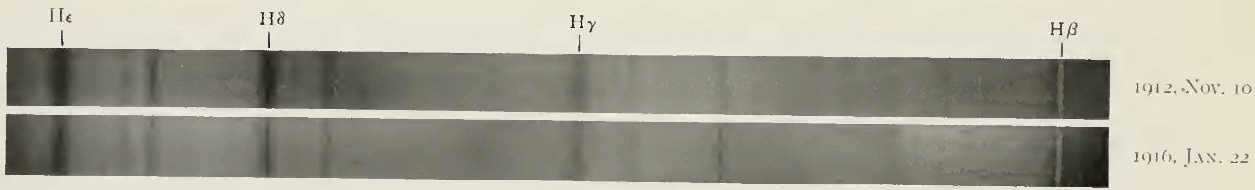

PLATE E. SPECTRA OF THE STAR, H. R. 985, SHOWING CHANGES IN Hε, Hδ, Hγ AND Hβ BETWEEN 1912 AND 1916

SPECTROSCOPIC OBSERVATIONS OF STARS OF CLASS Md.

By PAUL W. MERRILL

INTRODUCTION

A large majority of all stars, telescopic as well as naked-eye, shine continually with a steady light, but an occasional one, known as a variable star, is subject to fluctuations in brightness. As exceptions to the usual order, such objects, naturally, have been of great interest to all watchers of the skies, and much attention has been devoted to them by professional and amateur astronomers, resulting in the accumulation of a large amount of information concerning them.

Upon close scrutiny it is found that nearly all variable stars are periodic, that is, they repeat their cycles of change after more or less regular intervals. Moreover, they naturally divide into two rather distinct groups according to the length of this interval, one group having periods of a few days, and the other completing their cycles of mutation in about a year. To distinguish between the two groups conveniently, they are called short-period and long-period variables.

Eighty-five per cent of all the long-period variables are red stars whose spectra are characterized by absorption bands of titanium oxide and also contain bright hydrogen lines. Spectra of this kind are comprised in Secchi's third type, or are of Class Md in the Harvard system. Every star known to belong to this spectral class is without exception a variable of long or irregular period. The fact that such a spectrum always indicates this type of variability is a remarkable one which has never received a satisfactory explanation. The present paper deals with stars having spectra of this kind.

HISTORICAL

Light Variations.—The first historical discovery of stellar variability relates to a star of Class Md. It was made in 1596, before the invention of the telescope, by Fabricius who noted the apparent creation of a star in the constellation Cetus. It later proved to be a long-period variable with a change in brightness carrying it in less than six months from complete invisibility without optical aid to a rather conspicuous position among the naked-eye stars. In 1603, Bayer, in the course of assigning designations to the naked-eye stars and ignorant of the variability discovered by Fabricius, gave this star the Greek letter omicron, so that it is known today as *o* Ceti. On account of its wonderful changes in light it was later given the special name, Mira, by Hevelius.

As its characteristics are typical of stars of this kind, it naturally serves as the example of long-period variation. The period approximates a year in length; the variation in light is great, usually from four to seven magnitudes, i. e., an increase varying from forty to six hundred and thirty times its minimum brightness, not being perfectly regular either in time or limiting magnitudes. The rise to maximum is more rapid than the decline. The star is decidedly red in color.

The second historical discovery of a variable star, in 1669, was of the short-period star Algol, but the next three discoveries were long-period stars of Class Md, given in this table:

STAR	YEAR OF DISCOVERY	PERIOD
o Ceti	1596	332 days
R Hydræ	1670	425
χ Cygni	1696	406
R Leonis	1782	313

The four stars listed are all of this kind which were discovered prior to 1800. During the nineteenth century 223 were found, 131 of them during the decade 1890 to 1900, a fact which illustrates the efficiency of the new methods of photography and spectroscopy. From 1900 to 1911 inclusive, 136 additional members of this group were discovered, making a total of 363 variable stars definitely known to have spectra of Class Md. Lists for the years since 1911 are not available. Only 15 of these stars are ever brighter

than the sixth magnitude, or within the range of naked-eye observation. The writer has secured successful spectral photographs with the Ann Arbor 37½-inch reflector and attached spectrograph with reasonable exposure times down to magnitudes as low as 8.5. Within this limit there are 225 stars, most of which could not be profitably studied with less powerful apparatus. In any case, their observation is rather difficult on account of their faintness and variability. In many instances they are bright enough to be photographed for only a few weeks each year, at which time they may be in too close proximity to the sun for observation, so that the gathering of complete data for them would be a long program for a large observatory, and would necessarily require a station in the southern hemisphere since forty-six per cent of the 225 stars lie in the southern half of the sky.

While periodic in a general way, the successive cycles of long-period stars are by no means identical, so that it is impossible to predict exactly when the next maximum of a given star will occur, or exactly how bright it will be upon that occasion. This enhances the difficulty of observing such a star spectrographically and necessitates a special watch of each star near the predicted time of its maximum. The observing list, chosen from stars known to have reached a certain brightness in the past, is apt to contain stars whose maxima in any particular year are disappointingly faint.

Spectroscopic Observations.—Omicron Ceti, the brightest as well as the best known member of its group, has been by far the most extensively studied with the spectroscope. The continuous and absorption spectrum belongs to type III, as described by Secchi more than fifty years ago, having strong dark flutings which terminate abruptly on the violet side and shade off gradually in the other direction. The bright hydrogen lines were first detected, by means of photography, at Harvard, in 1886. The star has been photographed there at the time of nearly every maximum since that date, but complete descriptions of the photographs have never been published. Comparison with other similar stars early led to the following generalizations for variable stars of Class Md: at maximum the bright hydrogen lines are very strong relatively to the continuous spectrum; usually $H\gamma$ and $H\delta$ are strong, and $H\epsilon$ is especially weak; there are great differences in the relative intensities of the bright lines in different stars and even variations in the same star. Brief descriptions of many spectra of Class Md have been published by the Harvard College Observatory, referring largely to the bright lines. Ten subdivisions, Md 1-10, were used by Mrs. Fleming, apparently depending both upon the relative strength of the bright hydrogen lines, particularly $H\gamma$ and $H\delta$, and upon the appearance of the continuous and absorption background.

Numerous other observers have photographed the spectrum of *o* Ceti at various maxima, as follows:

Vogel	1896	Potsdam
Sidgreaves	1897–98	Stonyhurst
Campbell	1898	Lick Observatory
Stebbins	1902	Lick Observatory
Plaskett	1906–07	Ottawa
Slipher	1906–07	Lowell Observatory
Wright	1909	Lick Observatory

Vogel[1] found the bright lines of hydrogen broad and strong, and somewhat displaced to the red. i. e., indicating a motion of recession. The series was seen from $H\gamma$ to $H\iota$ with the exception of $H\epsilon$. No other bright lines were visible.

The following year the spectrum had much the same appearance on Sidgreaves' plates.[2] It remained substantially constant during two and a half months of observation, but there were changes in the relative intensities of different portions of the spectrum, showing that the blue light decreased during the interval as compared with the yellow green. Of the bright hydrogen lines, $H\gamma$ and $H\delta$ were extraordinarily brilliant, $H\epsilon$ was absent, and $H\beta$ uncertainly seen. He remarked upon this as follows: "But it is not easy to reconcile the comparatively weak absorption at this part of the band in Mira with its supposed absorbing action on the very energetic radiation of $H\beta$. * * * It seems more probable that *o* Ceti shows a condition of hydrogen radi-

[1] *Sitzungsberichte der Koeniglichen Preussichen Akademie der Wissenschaften zu Berlin*, 1896, p. 395.

[2] *Monthly Notices, R. A. S.*, *58*, 344, 1898.

ance not yet met with in the laboratory, in which $H\alpha$ and $H\beta$ have fallen out of the spectrum."

At the next maximum in 1898, portions of the spectrum were photographed with three-prism dispersion by Campbell[3]. The radial velocity from the dark lines was measured and appeared constant at +62km. per second. Bright $H\gamma$ and $H\delta$ were not monochromatic but broadened, at times appearing triple. Additional bright lines ascribed to iron were seen, which grew relatively stronger as the continuous spectrum faded. The bright lines, approximately consistent among themselves, gave a radial velocity some 15 km. less than that yielded by the absorption lines.

The spectrum of *o* Ceti was thoroughly studied during the decreasing phase in 1902, by Stebbins[4], at the Lick Observatory. His measures showed a difference of about 15 km. per second between the radial velocities derived from the bright lines and from the dark lines, in confirmation of the earlier observations by Campbell. Many details of the spectrum are recorded as studied with both high and low dispersion. An instructive diagram showing the relative intensities of numerous bright lines as the star waned is included. The changes are so great and of such a nature that their reality cannot be doubted.

The spectrum of *o* Ceti was also photographed by Plaskett[5] during December, 1906, and January, 1907, using three-prism dispersion. His radial velocities are in excellent agreement with those of Campbell and Stebbins. He confirmed the variations in the relative intensities of the emission lines. V. M. Slipher also secured spectrograms at this maximum[6], which are of particular interest and importance in that they contain the red end of the spectrum.

Observations which showed that the components of the triple bright $H\gamma$ line in the spectrum of *o* Ceti are not strongly polarized were made by Wright[7] in 1909. The multiple character is then not due to a magnetic field of constant direction.

[3] *Astrophysical Journal, 9,* 31, 1899.

[4] *Lick Observatory Bulletin, 2,* 78, 1903.

[5] *Journal, R. A. S., Canada, 1,* 45, 1907.

[6] *Astrophysical Journal, 25,* 66 and 235, 1907.

[7] *Lick Observatory Bulletin, 6,* 60, 1910.

Observations of χ Cygni are described by Eberhard in *Astrophysical Journal 18,* 198, 1903. Hydrogen and other bright lines were present and altered their relative intensities as the star waned, $H\delta$ decreasing and 4308Å Fe increasing in strength. Velocities from bright and dark lines were discrepant as in *o* Ceti. In conclusion he refers to the highly interesting fact that χ Cygni and *o* Ceti "exhibit a precisely identical behavior, both as to the spectrum and as to the variations of the spectrum; whence it is highly probable that this sort of spectrum is typical for the long-period variables of that class." This idea is borne out in several respects by observations to be described in the present paper.

In *Monthly Notices R. A. S., 72,* 546, 1912, Espin gave an account of visual observations by himself and Maunder of R Cygni, a star with a peculiar spectrum but resembling this general type. Attached to the article is a description of a few spectrograms of the star made by Wright at Mt. Hamilton.

Professor R. H. Curtiss, while at Lick Observatory, obtained numerous spectrograms of W Cygni[8], a star possessing a spectrum which at times comes within the limits of Class Md. Measurements of these plates by the writer are recorded in the present paper.

One of the most important investigations bearing upon the nature of these stars was made in the laboratory by Fowler[9]. His experiments identified the conspicuous and characteristic flutings seen in spectra of Class M with those produced in the outer portions of the titanium arc and presumably due to titanium oxide. A photograph of the spectrum of *o* Ceti by Slipher was compared by Fowler with a negative copy of one of his exposures upon the arc; the two are remarkably and convincingly similar.

Summary of Spectroscopic Observations.—Nearly all long-period variable stars show essentially similar spectra known as Class Md, consisting of a continuous spectrum with numerous absorption lines and the absorption flutings of titanium oxide, with the addition of the bright

[8] *Lick Observatory Bulletin, 3,* 41, 1904.

[9] *Proc. Roy. Soc., 73,* 219, 1904.

Mon. Not. R. A. S., 69, 508, 1909.

lines of hydrogen, which do not, in general, follow their laboratory intensities.

Two stars, *o* Ceti and χ Cygni, have been studied at the maximum phase, the former extensively. The bright lines, including a few due to other elements than hydrogen, show variable relative intensities, and are displaced to the violet about 0.25 Å with respect to the dark lines.

Radial velocities have been published for four stars:

o Ceti,
χ Cygni,
L_2 Puppis,[10]
R Cygni,

There is no evidence of variation in radial motion in any of the four.

No star has been followed spectroscopically through its entire cycle. The practical difficulties are the faintness of the stars at minimum, and the fact that the periods of many are almost a year so that a certain portion of the cycle is often lost for several successive years by the proximity of the sun.

ANN ARBOR OBSERVATIONS

The present observations were undertaken with the hope that they might be of value in two directions: first, to extend the investigations of *o* Ceti and χ Cygni, in a partial measure to numerous other stars for comparison, as tending to aid in the interpretation of this interesting type of variability; and, second, a determination of a considerable number of radial velocities as a contribution to our knowledge of the relation of these stars to those of other spectral classes. My observational material bears principally on the bright lines, and largely on those due to hydrogen. The exposures were often too short to record other bright lines or the continuous spectrum satisfactorily.

The Ann Arbor spectrograms were all obtained with the one-prism spectrograph in connection with the 37½-inch Cassegrain reflector. The first plates were secured with the instrument as described by Professor Curtiss in these *Publications*, Vol. 1, p. 37. On May 20, 1914, a prism of light flint glass was substituted for the original one of O:102 glass.[11] This prism was readjusted on Oct. 22, 1914, changing the dispersion somewhat.

Bright Lines.—There follows a record of the data yielded by the bright lines of forty-three stars, forty of them having been observed at Ann Arbor. The exposure time required here for a star of a given magnitude varied greatly with the character of the spectrum as well as with the observing conditions. For stars not fainter than 8.5 visual magnitude, good images of the stronger bright lines could usually be obtained in two hours. The great relative intensity of the emission lines is illustrated by the fact that they are frequently well exposed on plates where the continuous spectrum is very weak or invisible.

The principal comparison lines (titanium spark) together with the bright stellar lines are given below with their tabular micrometer settings for a screw of 0.5 mm. pitch. The origins of the stellar lines are indicated. In a few instances the wave-lengths first used were changed slightly in the following tables; in these cases the value is given to the tenth of an angstrom only.

Magnitude data from the American Association of Variable Star Observers has been an aid in making out the program since many of the stars could be observed only within a few weeks of maximum, and that epoch cannot be satisfactorily predicted. I am indebted to the president, Mr. William Tyler Olcott, and especially to Mr. Chas. B. Lindsley, who sent a considerable number of current magnitude determinations of the stars on my list.

The data appearing in the first line for each star are taken from the *Annals of the Harvard College Observatory*. The number appearing before the name of the star indicates the star's position; the first and second figures give the hour of right ascension, the third and fourth the minute, the fifth and sixth the degree of declination; italics denote southern declination. The time of the maximum was kindly supplied, in most cases, by Mr. Leon Campbell, through the

[10] *Lick Observatory Bulletin*, 7, 127. 1913.

[11] *Detroit Observatory Publications*, I, 77, 1915.

[12] Clerke, *Problems in Astrophysics*, p. 362.

[13] Campbell, *Stellar Motions*, p. 303.

courtesy of Professor Pickering. The column headed "Phase" gives the fraction of the period, before (—), or after (+), the time of maximum. The magnitude of the variable was estimated at the time of each spectroscopic observation by comparing it with adjacent stars in the four inch finder, using, in most cases, Hagen's magnitudes for the comparison stars. The estimated magnitude appears immediately after the date; if considered unreliable, the value is enclosed in parentheses. The intensities of the bright lines are roughly absolute: 1 indicating the weakest image of the rather wide slit, which could be measured with accuracy; "v" means visible, but weaker than 1. The velocities are in kilometers per second; a colon indicates uncertainty.

TABLE I.

WAVE-LENGTH	PRIOR TO 1914, MAY 22		MAY 22—OCT. 22		AFTER 1914, OCT. 22	
	MICR.	DV/DR	MICR.	DV/DR	MICR.	DV/DR
4981.93	36.097		37.616		39.428	
4885.27	39.192		40.531		42.360	
4861.53 Hβ	39.988	1825	41.280	1938	43.113	1926
4856.1	40.170		41.451		43.284	
4841.04	40.686		......		43.773	
4512.93	53.584		......		......	
4399.90	58.938		59.042		61.015	
4367.8	60.561		60.557		62.540	
4340.63 Hγ	61.975	1311	61.875	1406	63.874	1394
4338.1	62.107		62.000		64.000	
4163.87	72.132		71.346		73.425	
4112.8	75.421		74.405		76.505	
4101.98 Hδ	76.150	1091	75.078	1174	77.186	1157
4082.63	77.454		76.295		78.413	
4078.65	77.727		76.548		78.668	
3924.69	89.272		......		89.456	
3905.66 Si	90.847	917	88.695	993	90.925	984
3904.93	90.908		88.751		90.982	
3889.20 Hζ	92.239	903	89.978	979	92.222	969
3882.73	92.794		90.490		92.739	

001755. T CASSIOPEIAE.

R.A. $0^h\ 17^m.8$; Decl. $+55°\ 14'$.

Class, Md8; Magnitude, 6.9 to 12.3. Period, 445 days. Time of maximum, double, 1914 Nov. 13, magnitude 8.3; 1915 March 13, magnitude 8.4.

G. M. T.	MAG.	PHASE	VELOCITY AND INTENSITY Hδ
1914 Nov. 27.61	8.5	0.0±	−27: underexposed.

001838. R ANDROMEDAE.

R.A. $0^h\ 18^m.8$; Decl. $+38°\ 1'$.

Class, Md2. Magnitude, 6.0 to 14.9. Period, 411 days. Time of maximum, May 25, 1915.

G. M. T.			MAG.	PHASE.	VELOCITY AND INTENSITY Hβ	Hγ	Hδ	MEAN
1915	May	30.84	7.3	0.0	−29:(1½)	−18::(v)	−38:(v)	−30
	July	5.81	8.5	+0.1	−39 (1½)	(v)	−45:(v)	−41
							Mean,	−36

Both plates underexposed, and measures not very accurate.

012502. R PISCIUM.

R.A. $1^h\ 25^m.5$; Decl. $+2°\ 22'$.

Class, Md7. Magnitude, 7.6 to 13.5. Period, 344 days. Time of maximum, 1914 Nov. 14.

G. M. T.			MAG.	PHASE.	VELOCITY AND INTENSITY Hβ	Hγ	Hδ	Hζ	MEAN
1914	Nov.	6.69	8.3	0.0	−47::(½)	−58 (5)	−59 (4)	...	−58
	Nov.	22.69	8.2	0.0	−66: (1½)	−58 (5½)	−59 (5)	(v)	−59
								Mean,	−59

021024. R ARIETIS.

R.A. $2^h\ 10^m.4$; Decl. $+24°\ 35'$.

Class, Md4. Magnitude, 7.5 to 13.7. Period, 187 days. Time of maximum, September 7, 1914.

G. M. T.			MAG.	PHASE.	VELOCITY AND INTENSITY Hβ	Hγ	Hδ	MEAN.
1914	Sept.	16.77	8.6	0.0	+106 (4)	+ 99 (4−)	+ 99 (2)	+100
	Sept.	24.79	8.5	+0.1	+101:(2−)	+ 98 (2)	+106:(1)	+100
	Sept.	26.78	8.5	+0.1	+102 (3−)	+109 (3)	+ 94 (2)	+102
							Mean,	+101

021143. W ANDROMEDAE.

R.A. $2^h\ 11^m.2$; Decl. $+43°\ 50'$.

Class, Md. Magnitude, 6.5 to 14.0. Period, 395 days. Time of maximum, February 23, 1915.

G. M. T.			MAG.	PHASE.	VELOCITY AND INTENSITY Hγ	Hδ	Hζ	MEAN
1915	Feb.	28.63	7.7	0.0	−40 (2)	−47 (5)	(v)	−44

021403. *o* CETI.

R.A. 2^h $14^m.3$; Decl. $-3°$ 26′.

Class, Md9. Magnitude, 1.7 to 9.6. Period, 332 days. Time of maximum, February 1, 1915.

G. M. T.	MAG.	PHASE	Hγ	Hδ	Hζ	Hη	Hθ	Hι	MEAN
			VELOCITY AND INTENSITY						
1914 Dec. 25.48	5.6	—0.1	+58(1+)	+51(2)					+54
25.57	5.6	—0.1	+56(3)	+46(5)					+52
1915 Jan. 29.55	3.7	0.0	+55(7)	+47(12)	+64(3)	+69(1+)	+34(1—)	+64(1)	+53
Nov. 5.68	6.6	+0.8	(Barely v)	(1)					....
12.66	6.2	+0.8	+57(1)	+42(3)					+49
								Mean,	+52

A series of three-prism measures in 1897-1898 by Campbell and Wright (*Astrophysical Journal* 9, 32, 1899) of the bright Hγ line yielded a mean radial velocity of + 55 km. The velocity from bright Hδ was + 49 km. Measures in November, 1898, on four bright lines gave a mean of only + 44 km. In 1902, Stebbins (*Lick Observatory Bulletin*, 2, 93, 1902) found the mean of three bright lines with three prisms to be + 44 km., and the mean of four with one prism to be + 48 km.

The mean velocity given by Plaskett from measures of the bright Hγ line on fourteen three-prism plates, taken in December 1906 and January 1907, is + 46.1 km. (*Journal R. A. S., Canada*, 1, 53, 1907).

REMARKS ON ANN ARBOR SPECTROGRAMS.

1915 Jan. 29. The bright lines are somewhat stronger than on December 25.

1915 Nov. 5, 12. The bright lines are weak not showing the contrast with the continuous spectrum exhibited by the other plates. On Nov. 5, Hγ is so weak as not to be readily visible. It is easily seen on Nov. 12, but is not conspicuous as it is not much stronger than the adjacent continuous spectrum. This is strikingly at variance with its appearance on my earlier plates, and as observed by others. For instance, referring to three-prism observations in 1897 and 1898, Campbell says "If an exposure of an hour was required for recording the dark line spectrum, an exposure of two minutes under the same conditions would record the Hγ band," and in January 1907, Plaskett estimated "that the bright Hβ had an intensity about 15 times that of the continuous spectrum in that region, Hγ about 25 times and Hδ at least 50 times." The star was considerably past maximum at this time.

050953. R AURIGAE.

R.A. 5^h $9^m.2$; Decl. $+53°$ 28′.

Class, Md. Magnitude, 6.5 to 13.8. Period, 459 days. Time of maximum, April 12, 1915.

G. M. T.	MAG.	PHASE	Hγ	Hδ	Hζ
			VELOCITY AND INTENSITY		
1915 March 7.70	8.6	—0.1		—14 (2)	(v)
12.72	8.5	—0.1	(barely v)	+ 1 (2)	
			Mean,	— 9:	

061702. V MONOCEROTIS.

R.A. $6^h\ 17^m.7$; Decl. $-2°\ 9'$.

Class, Md7. Magnitude, 7.2 to less than 12.9. Period, 332 days. Time of Maximum, February 17, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY				
					Hγ	Hδ	Hζ	Hη	MEAN.
1915	Feb.	19.64	7.6	0.0	+14 (3)	+12 (5)	+21 (1)	(v)	+15
		19.68	7.6	0.0	+26 (1)	+12 (2)			+19
								Mean,	+16

065355. R LYNCIS.

R.A. $6^h\ 53^m.0$; Decl. $+55°\ 28'$.

Class, Md1. Magnitude, 7.0 to 13.8. Period, 379 days. Time of maximum, March 4, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY			
					Hβ	Hγ	Hδ	MEAN
1915	Feb.	28.70	8.2	0.0	+16 (8)	+ 9 (3)	—6 (1)	+ 9
		28.74	8.2	0.0	+20:(7)	+16 (3½)	—3 (1)	+10
	Mar.	12.78	8.1	0.0	+12 (5½)	+19 (3)	(½)	+16
		28.71	8.3	+0.1	+ 9 (3)	+11 (2)		+10
							Mean,	+11

071044. L_2 PUPPIS.

R.A. $7^h\ 10^m.5$; Decl. $-44°\ 29'$.

Class, Md6. Magnitude, 3.4 to 6.2. Period, 140 days. Observations by D. O. Mills Expedition, Santiago, kindly communicated by Director Campbell, as follows:

Two-prism plates 1911. Bright lines are single and narrow.	
Br. Hγ and Hδ	+49
Br. Hγ and Hδ	+49
Br. Hγ	+57
One-prism plates in 1914.	
Br. lines	+50
Br. lines	+51
Mean of all	+51

084803. S HYDRAE.

R.A. $8^h\ 48^m.4$; Decl. $+3°\ 27'$.

Class, Md4. Magnitude, 7.5 to 13.0. Period, 256 days. Time of maximum, April 3, 1915.

G. M. T.	MAG.	PHASE	VELOCITY AND INTENSITY				
			Hβ	Hγ	Hδ	Hζ	MEAN
1915 March 26.61	8.3	0.0	+74 (1½)	+79 (3)	+74 (3—)	+77 (½)	+77

085008. T HYDRAE.

R.A. $8^h\ 50^m.8$; Decl. $-8°\ 46'$.

Class, Md4. Magnitude, 7.0 to 13.1. Period, 289 days. Time of maximum, February 22, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN
1915	Feb.	19.73	8.0	0.0	—10 (2)	— 9 (2+)	—10
		26.67	8.0	0.0	—13 (2)	—14 (3)	—14
						Mean,	—12

093934. R LEONIS MINORIS.

R.A. 9h 39m.6; Decl. +34° 58′.

Class, Md8. Magnitude, 7.0 to 13.0. Period, 370 days. Time of maximum, January 14, 1915.

G. M. T.	MAG.	PHASE	Hγ	Hδ	3905	Hζ	Hη	Hθ	Hι	MEAN
			VELOCITY AND INTENSITY							
1915 Jan. 29.68	8.0	0.0	+5(2)	−6(5)		(v)				−1
29.76	8.0	0.0	−13(2)	−13(6)		(1)				−13
Feb. 19.83	8.2	+0.1	−8(4+)	−10(9)	−3(1)	+5(3)	+4(2)	−9(1)	+4(⅔)	−4
									Mean,	−6

1915 Feb. 19.83, bright Fe 4202.20 (Rowland) gives a velocity of +1km.

094211 R LEONIS.

R.A. 9h 42m.2; Decl. +11° 54′.

Class, Md10. Magnitude, 4.6 to 10.5. Period, 313 days. Time of maximum, February 22, 1914.

G. M. T.	MAG.	PHASE	Hγ	4202	Hδ	3905	Hζ	MEAN
			VELOCITY AND INTENSITY					
1913 Dec. 14.98	8.6	−0.2			(v)			
21.88	8.4	−0.1			0(2)			0
1914 Feb. 1.80	6.7	0.0	0(3)		+4(9)			+2
27.74	6.7	+0.1	−2(3)	(1)	0(7)		+5:(1)	0
28.76	6.8	+0.1	−4(5)	−1(2)	0(11)	+2(1)	+7:(2)	0
Mar. 14.74	6.8	+0.1	−3(5)	+3(2)	−1(10)	(v)	+3 (1)	0
19.63	6.85	+0.2	−3(1)		−5(2+)			−4
Apr. 11.60	8.0	+0.2	−1(4)	−1(2+)	+4(7)		(v)	0
30.61	8.1	+0.3	(v)		(v)			
							Mean,	0.0

Observation by Lick Observatory, kindly communicated by Director Campbell. Three-prism plate, bright Hγ, −10 km.

103769. R URSAE MAJORIS.

R.A. 10h 37m.6; Decl. +69° 18′.

Class, Md8. Magnitude, 7.0 to 13.5. Period, 302 days. Times of maximum, May 14, 1914, March 1, 1915.

G. M. T.	MAG.	PHASE	Hβ	Hγ	Hδ	3905	Hζ	Hη	MEAN
			VELOCITY AND INTENSITY						
1914 May 30.64	8.1	+0.1		+27(6)	+20(9)		+33 (2−)	(v)	+25
1915 Feb. 19.83	(7.0)	0.0		+25(7)	+23(8)	(v)	+35:(2)		+26
26.74	(6.8)	0.0	+10::(v)	+17(5)	+21(7)		+28 (1+)	(v)	+19
								Mean,	+23

A narrow maximum, possibly a bright line, was measured on 1915, February, 26.74, at 4138.75, Å (reduced to zero velocity).

121418. R CORVI.

R.A. 12^h $14^m.4$; Decl. — 18° 42′.

Class, Md6. Magnitude, 7.5 to 12.6. Period, 318 days. Time of maximum, May 19, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN
1915	May	9.68	7.6	0.0	—36 (2)	—40 (2+)	—39
	June	4.62	7.8	+0.1	—29 (1)	—28 (1+)	—29
						Mean,	—34

123160. T URSAE MAJORIS.

R.A. 12^h $31^m.8$; Decl. + 60° 2′.

Class, Md6. Magnitude, 6.4 to 13.1. Period, 257 days. Time of maximum, April 27, 1914.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN.
1914	Apr.	11.75	8.3	—0.1	—106 (2)	—112 (3)	—109
	May	2.68	8.1	0.0	—101 (2)	—110 (3)	—105
		16.74	8.4	+0.1	—107 (1)	—108 (1½)	—107
						Mean,	—107

123307. R VIRGINIS.

R.A. 12^h $33^m.4$; Decl. + 7° 32′.

Class, Md5. Magnitude, 6.4 to 12.1. Period, 146 days. Time of maximum, April 14, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN
1915	Mar.	28.79	7.9	—0.1	—23 (3)	—42 (4)	—32
	Apr.	16.66	7.9	0.0	—27 (1)	—26 (⅔)	—27
	May	7.60	8.1	+0.1	—46 (2—)	—40 (1)	—44
						Mean,	—35

123961. S URSAE MAJORIS.

R.A. 12^h $39^m.6$; Decl. + 61° 38′.

Class, Md4. Magnitude, 7.3 to 12.5. Period, 226 days. Time of maximum, June 19, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hβ	Hγ	MEAN
1915	Apr.	25.66	8.5	—0.2	—2::		
	May	7.69	8.5	—0.2	—6::		
	June	11.68	8.1	0.0	+6 (2)	0 (2—)	+2
	June	25.66	7.8	0.0	+2 (3)	—4 (4)	—2
						Mean,	—1

132422. R HYDRAE.

R.A. $13^h\ 24^m.2$; Decl. $-22°\ 46'$.

Class, Md. Magnitude, 4.0 to 9.8. Period, 425 days. Time of maximum, April 1, 1914. May 7, 1915.

G. M. T.	MAG.	PHASE	Hβ	Hγ	Hδ	Hζ	Hη	MEAN
1914 May 28.65	(6.6)	+0.1		—22(3)	—24(5)	(v)		—23
1915 May 30.61	4.9	+0.1	—28(2)	—32(5)	—27(7)	—15(2)	(1)	—27
30.64	4.9	+0.1	—28(1)	—28(5)	—30(7)	(1)	(v)	—29
							Mean,	—26

A narrow maximum, possibly a bright line, measured on 1915, May, 30.61 at 4202.38 Å (reduced to zero velocity.) If this is Fe 4202.20 (Rowland), it gives a velocity of — 15 km. reduced to sun.

Observations by Lick Observatory, kindly communicated by Director Campbell: two three-prism plates, bright Hγ. — 26 km.

134440. R CANUM VENATICORUM.

R.A. $13^h\ 44^m.6$; Decl. $+40°\ 2'$.

Class, Md9. Magnitude, 6.1 to 12.7. Period, 333 days. Time of maximum, April 2, 1914. March 5, 1915.

G. M. T.	MAG.	PHASE	Hγ	Hδ	Hζ	Hη	MEAN
1914 May 30.74	(8.2)	+0.2	—24(2)	—20(3)			—22
June 11.66	8.1	+0.2	—13(1)	—22(1½)			—19
1915 Mar. 26.69	7.3	+0.1	—29(2)	—24(5)	(1)	(v)	—26
26.74	7.3	+0.1	—32:(2)	—25(5)	—13(1+)	(v)	—25
						Mean,	—24

142539. V BOOTIS.

R.A. $14^h\ 25^m.7$; Decl. $+39°\ 18'$.

Class, Md7. Magnitude, 6.9 to 11.0. Period, 256 days. Time of maximum, May 24, 1914, Feb. 29, 1915.

G. M. T.	MAG.	PHASE	Hγ	Hδ	Hζ	Hη	MEAN
1914 May 28.74	7.75	0.0	—39 (1)	—31(2—)			—34
1915 Feb. 28.90	7.6	0.0	—48 (2)	—44(3½)	—46(1—)	(v)	—46
Mar. 12.88	7.7	+0.1	—39:(2)	—41(3)			—40
						Mean,	—41

143227. R BOOTIS.

R.A. $14^h\ 32^m.8$; Decl. $+27°\ 10'$.

Class, Md4. Magnitude, 6.6 to 12.9. Period, 223 days. Time of maximum, April 5, 1915.

G. M. T.	MAG.	PHASE	Hγ	Hδ	Hζ	MEAN
1915 Feb. 26.85	8.2	—0.2	—52(5)	—57(5—)		—54
28.81	8.3	—0.2	—49(5)	—55(4)	(v)	—52
Mar. 7.81	7.9	—0.1	—53(5)	—62(4)		—58
26.81	7.3	0.0	—59(6)	—57(5)	(1)	—58
Apr. 16.73	7.6	+0.1	—60(3)	—65(2)		—62
					Mean,	—57

151731. S CORONAE.

R.A. $15^h\ 17^m.3$; Decl. $+31°\ 44'$.

Class, Md9. Magnitude, 6.7 to 12.7. Period, 361 days. Time of maximum, February 26, 1914, February 13, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY								
					Hβ	Hγ	Hδ	3905	Hζ	Hη	Hθ	Hι	MEAN
1914	Apr.	9.90	8.6	+0.1		—13(2)	—24(5)						—21
1915	Feb.	26.93	7.3	0.0	—22(2)	—26(10)	—26(14)	—24(1)	—13(3+)	—13(2)	(1)	—12(1+)	—22
	Mar.	7.80	7.4	+0.1	—32:(1½)	—22(6)	—25(9)	—18:(1—)	—15(4)	—15(2+)	—27(1+)	— 8(1+)	—21
		7.94	7.4	+0.1	(1—)	—25(8)	—26(12)	(v)	—17:(2)	(1)	(v)	(v)	—24
												Mean,	—22

A narrow maximum, possibly a bright line, was measured as follows:—

1915	Feb. 26.93	4138.95Å	Wave length reduced to zero velocity.
	Mar. 7.80	4138.91	

This line was also measured by the writer in the spectrum of 103769 R Ursae Majoris, 4138.75 Å, and by Plaskett in the spectrum of *o* Ceti, 4138.78 Å (*Journal R. A. S., Canada, 1*, 55, 1907).

154615. R SERPENTIS.

R.A. $15^h\ 46^m.1$; Decl. $+15°\ 26'$.

Class, Md8. Magnitude, 5.6 to 13. Period, 357 days. Time of maximum, April 1, 1914, April 12, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY			
					Hβ	Hγ	Hδ	Hζ	MEAN
1914	Apr.	11.88	(6.5)	0.0	+ 5(7)	+13(14)	+9(10)	(v)	+10
		30.72	(6.3)	+0.1	+13:(1)	— 3(3)	+9(3)		+ 5
	May	2.79	(6.3)	+0.1	(1½)	(5)	(4)		Comps. poor
		14.70	7.0	+0.1	(1)	+ 7(4)	+5(4)		+ 6
1915	Mar.	26.89	(7.6)	0.0	(?)	+19(5)	+5(8)	+22:(1)	+ 9
								Mean,	+ 8

162119. U HERCULIS.

R.A. $16^h\ 21^m.4$; Decl. $+19°\ 7'$.

Class, Md(8). Magnitude, 6.4 to 12.0. Period, 403 days. Time of maximum, May 5, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN
1915	Apr.	16.81	7.7	0.0	—35(1)	—43(4)	—40
		25.77	7.2	0.0	—43(1—)	—40(3)	—41
	May	7.79	7.6	0.0	—34(2)	—47(5)	—40
						Mean,	—40.4

The class of this star appears in *Annals H. C. O.*, Vol. 56, p. 203 as Md. However, from an examination of Mrs. Fleming's record book, I believe that she meant to classify it as Md8. This is in agreement with both the Harvard and Ann Arbor spectra.

163137. W HERCULIS.

R.A. $16^h\ 31^m.7$; Decl. $+37°\ 32'$.

Class, Md5. Magnitude, 7.8 to 13.5. Period, 280 days. Time of maximum, July 11, 1915.

G. M. T.	MAG.	PHASE	VELOCITY AND INTENSITY Hγ	Hδ	MEAN
1915 June 11.80	8.6	−0.1	−50(1½)	−62(2)	−57
13.70	8.5	−0.1	−61(2)	−59(3−)	−60
				Mean,	−59

164715. S HERCULIS.

R.A. $16^h\ 47^m.4$; Decl. $+15°\ 7'$.

Class, Md6. Magnitude, 7.3 to 12.6. Period, 308 days. Time of maximum, July 28, 1914, May 26, 1915.

G. M. T.	MAG.	PHASE	VELOCITY AND INTENSITY Hβ	Hγ	Hδ	Hζ	MEAN
1914 Aug. 8.66	7.8	0.0		−15(1)	−23(1+)		−21
15.69	7.7	+0.1	(1−)	−22(3)	−22(3)		−22
1915 May 30.69	(7.4)	0.0		−21(1)	−22(2)	(v)	−21
						Mean,	−21.3

170215. R OPHIUCHI.

R.A. $17^h\ 2^m.0$; Decl. $-15°\ 58'$.

Class, Md8. Magnitude, 7.1 to 13.6. Period, 302 days. Time of maximum, June 24, 1915.

G. M. T.	MAG.	PHASE	VELOCITY AND INTENSITY Hγ	Hδ	MEAN
1915 June 20.73	7.6	0.0	−64 (1)	−59 (1½)	−61
27.70	7.6	0.0	−54 (3)	−59 (3)	−57
				Mean,	−59

171401. Z OPHIUCHI.

R.A. $17^h\ 14^m.5$; Decl. $+1°\ 37'$.

Class, Md(2). Magnitude, 7.5 to 12.5. Period, 348 days. Time of maximum, May 27, 1914, May 2, 1915.

G. M. T.	MAG.	PHASE	VELOCITY AND INTENSITY Hβ	Hγ	Hδ	MEAN
1914 June 11.76	8.0	0.0	(1−)	− 86:(1)	−80:(1½)	−83
18.74	7.8	+0.1	−103:(1)	− 84 (1½)	−92:(v)	−89
July 2.66	8.1	+0.1	− 97:(2)	−102 (3)	−95 (1)	−99
1915 May 30.76	7.8	−0.1	− 98 (3)	− 92 (2)	−99:(1)	−96
					Mean,	−93

180531. T HERCULIS.

R.A. $18^h\ 5^m.3$; Decl. $+31°\ 0'$.

Class, Md3. Magnitude, 7.2 to 13.6. Period, 165 days. Time of maximum, Sept. 27, 1914; March 3, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY			
					Hβ	Hγ	Hδ	MEAN
1914	Sept.	16.60	8.4	—0.1		—135 (2)	—131 (2+)	—133
		24.60	(8.5)	0.0		—117:(2—)	—123:(2)	—120
	Oct.	2.63	8.3	0.0		—132 (2)	—125 (2)	—129
1915	Mar.	7.90	8.0	0.0	—138:(2)	—132 (4—)	—133 (3)	—132
							Mean,	—130

181136. W LYRAE.

R.A. $18^h\ 11^m.5$; Decl. $+36°\ 38'$.

Class, Md. Magnitude, 7.6 to 12.5. Period, 197 days. Time of maximum, 1915, Jan. 14.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY			
					Hβ	Hγ	Hδ	MEAN
1914	July	9.67	8.2	—0.0	(v)	—184 (2+)	—198 (2—)	—191
		9.78	8.2	—0.0	—183 (1+)	—179 (3)	—184 (2)	—182
		18.64	7.7	+0.1	—172:(1)	—184 (2)	—191 (2—)	—184
							Mean,	—186

It is an interesting coincidence, showing the great velocity of approach, that the bright Hγ line lies very nearly between the two components of the titanium comparison line 4338.10 Å. The bright hydrogen lines appear monochromatic, i. e., no wider than comparison lines of equal strength.

183308. X OPHIUCHI.

R.A. $18^h\ 33^m.6$; Decl. $+8°\ 44'$.

Class, Md8. Magnitude, 6.5 to 9.0. Period, 335 days. Time of maximum, Nov. 3, 1914, Oct. 9, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY			
					Hγ	Hδ	Hζ	MEAN
1914	Nov.	27.48	7.0	+0.1	—95:(1)	—89:(1—)		—91
1915	June	4.73	8.5	—0.4	Faint continuous; no bright lines.			
	July	5.67	8.1	—0.3		—85:		—85
	Aug.	6.67	7.6	—0.2	—76::(½)	—84 (2+)	—60::(v)	—83
	Aug.	9.63	7.55	—0.2	—93::(½)	—86 (2)	(v)	—86
							Mean,	—86

1915 July 5.67, bright Hδ does not appear monochromatic, being sharper on the violet edge.

193311. RT AQUILAE.

R.A. $19^h\ 33^m.3$; Decl. $+11°\ 30'$.

Class, Md9. Magnitude, 8.0 to <13. Period, 326 days. Time of maximum, Aug. 4, 1914.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN
1914	July	18.76	8.2	—0.1	—51 (2)	—61 (3)	—55
		25.66	8.3	0.0	—48 (2)	—58 (3½)	—54
		25.77	8.3	0.0	—50 (3)	—59 (4)	—54
						Mean,	—54.2

193449. R CYGNI.

R.A. $19^h\ 34^m.1$; Decl. $+49°\ 58'$.

Class, Peculiar. Magnitude, 6.6 to 13.9. Period, 426 days. Observations by Wright at Lick Observatory. *Mon. Not. R. A. S., 72,* 548, 1912, as follows:

		PHASE	VELOCITY AND INTENSITY				
			Hα	Hβ	Hγ	Hδ	MEAN
1911 Dec.	5	+		—43	—30	—10:	—30
	11	+		—43 (10)	—30 (4)	—33 (2)	—34
1912 Jan.	13	+	—78::(10+?)	—56 (10)			
			Mean,	—47	—30	—26	—34

Several other bright lines were suspected.

194048. RT CYGNI.

R.A. $19^h\ 40^m.8$; Decl. $+48°\ 32'$.

Class, Md5. Magnitude, 6.7 to 12.0. Period, 190 days. Time of maximum, Oct. 2, 1914, April 12, 1915.

G. M. T.		MAG.	PHASE	VELOCITY AND INTENSITY				
				Hβ	Hγ	Hδ	Hζ	MEAN
1914 Sept.	24.67	7.6	0.0	—140: (2+)	—123 (4)	—129 (3)	—116::(½)	—127
	24.73	7.6	0.0	—135::(1)	—125 (3—)	—127 (2)		—127
	26.70	(7.6)	0.0	—130 (2)	—129 (4)	—119 (3)		—125
Oct.	11.58	7.4	+0.1	—113::(2—)	—129 (4)	—129 (3)		—128
							Mean,	—126.8

Five plates were obtained by Frost and Parkhurst during the first half of December, 1905. Bright Hγ and Hδ gave a radial velocity of — 100 km. *Publications Astronomical and Astrophysical Society of America, 1,* 244, 1910.

194632. χ CYGNI.

R.A. $19^h\ 46^m.7$; Decl. $+32°\ 40'$.

Class, Md6. Magnitude, 4.0 to 13.5. Period, 406 days. Time of maximum, Dec. 13, 1914.

G. M. T.		MAG.	PHASE	VELOCITY AND INTENSITY					
				Hβ	Hγ	Hδ	Hζ	Hη	MEAN
1914 Nov.	27.52	5.1	0.0	—17 (2+)	—14 (3)	—20 (5)	—15 (1)	(v)	—16
	27.55	5.1	0.0	—24 (2½)	—13 (3)	—21 (5+)	(v)		—18
								Mean,	—17

Eberhard (*Ap. J., 18,* 198, 1903) records velocities from the bright lines as follows:—

1901;	26 plates from Aug. 2 to Nov. 23.	Hγ	— 19.7 km.
	9 plates from Sept. 7 to Nov. 23.	Fe 4308	— 20.3
1902;	18 plates from Sept. 22 to Dec. 12.	Hγ	— 21.0

Hγ was hazy toward the red as was also Hδ. From 1901, Aug. 2 until Sept. 19, Hδ was considerably stronger than Hγ; from Oct. 3 to 15, Hγ and Hδ differed little from each other. On Oct. 26 they were equal; and on Nov. 9 and 23 Hγ was brighter than Hδ. The Fe line λ 4308 increased in brightness the fainter the star became. Other bright lines were observed; Hγ, Hδ, Hζ, Hθ, Hι, 3905.8 Si?, Fe 4402 and other Fe lines.

205923. R VULPECULAE.

R.A. $20^h\ 59^m.9$; Decl. $+23°\ 26'$.

Class, Md6. Magnitude, 7.5 to 12.1. Period, 137 days. Time of maximum, June 16, 1914, Nov. 2, 1914.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY			
					Hβ	Hγ	Hδ	MEAN
1914	May	30.84	8.4	—0.1		—15 (1½)	— 5:(1)	—12
	June	25.78	8.3	+0.1	—9:(½)	—21 (1½)	—27 (1)	—22
	July	4.81	8.7	+0.1		0::(v)	—13:(v)	—10
							Mean,	—17

210868. T CEPHEI.

R.A. $21^h\ 8^m.2$; Decl. $+68°\ 5'$.

Class, Md9. Magnitude, 5.1 to 10.5. Period, 387 days. Time of maximum, Nov. 13, 1914.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY					
					Hγ	Hδ	Hζ	Hη	Hθ	MEAN
1914	Nov.	6.56	(6.7)	0.0	—36 (2—)	—33 (4)	—22 (1)	(v)		—32
		6.60	(6.7)	0.0	—28 (3)	—31 (5+)	—20 (2—1)	(v)	(v)	—29
									Mean,	—30

213244. W CYGNI.

R.A. $21^h\ 32^m.2$; Decl. $+44°\ 56'$.

Class, Mc. Magnitude, 5.0 to 6.7. Period, 132 days. The following are measures made by the writer of plates taken by Professor R. H. Curtiss at the Lick Observatory in 1903, with spectrograph I. See *Lick Bulletin 3*, 41, 1904. I am indebted to Professor Curtiss and to Director Campbell for the opportunity of using them.

			RADIAL VELOCITY		
			Hγ	Hδ	MEAN
1903	Aug.	3	—21	—18	—19
	Aug.	7	—27	—36	—31
	Aug.	26	—24	—36	—30
	Sept.	13		—23	—23
				Mean,	—26

NOTES ON BRIGHT HYDROGEN LINES FROM THESE AND OTHER PLATES.

1903 July 19 Bright lines weak, if present.
Aug. 3 Hγ3, Hδ4, both showing fair contrast with the background.
Aug. 9 Probably the same as Aug. 3.
Aug. 14 Hγ4, Hδ5, contrast a little stronger.
Aug. 17 Contrast slightly stronger.
Aug. 26 Contrast slightly less.
Sept. 4 Contrast of bright lines decidedly less than on Aug. 26. The bright lines are not sharply distinguished from the background.
Sept. 6 About the same as Sept. 4.
Sept. 13 Hγ is weak, if present, not being as strong as several spaces of the continuous spectrum near-by. Bright Hδ is just seen.
Sept. 23–Dec. 28. (Ten plates.) Bright lines not distinguishable; very weak, if present.

The times of maximum were "early in August and in the middle of December." Minimum occurred about October 12. It appears then that bright lines may *or may not* be seen as the star reaches maximum.

An underexposed plate taken at Ann Arbor on July 2, 1914, shows Hδ, and possibly also Hγ, faintly bright.

231425. W PEGASI.

R.A. $23^h\ 14^m.8$; Decl. $+25°\ 44'$.

Class, Md8. Magnitude, 7.5 to 13.5. Period, 342 days. Time of maximum, July 6, 1914.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY		
					Hγ	Hδ	MEAN
1914	July	25.85	7.8	+0.1	−39 (1)	−40 (3)	−40
		30.78	7.8	+0.1	−30 (1)	−32 (3)	−31
		30.86	7.8	+0.1	−31 (1)	−33 (3½)	−33
						Mean,	−35

231508. S PEGASI.

R.A. $23^h\ 15^m.5$; Decl. $+8°\ 2'$.

Class, Md8. Magnitude, 7.8 to 12.9. Period, 318 days. Time of maximum, July 16, 1915.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY				
					Hβ	Hγ	Hδ	Hζ	MEAN
1915	June	25.81	8.3	−0.1	(v)	−4 (4)	−9 (5)	(v)	−6
		27.81	8.2	−0.1		−7 (5)	−9 (4)	(v)	−8
								Mean,	−7

235350. R CASSIOPEIAE.

R.A. $23^h\ 53^m.3$; Decl. $+50°\ 50'$.

Class, Md8. Magnitude, 5.3 to 12.8. Period, 432 days. Time of maximum, Oct. 4, 1914.

G. M. T.			MAG.	PHASE	VELOCITY AND INTENSITY						
					Hβ	Hγ	Hδ	3905	Hζ	Hη	MEAN
1914	Aug.	15.77	(7.5)	−0.1		+25:(1)	+12 (2+)				+16:
	Sept.	9.68	6.5	−0.1	+10 (v)	+ 9 (15)	+ 8 (22)	+10 (1)	+15 (3+)	(v)	+ 9.7
		9.72	6.5	−0.1	(?)	+10 (12)	+ 6 (18)	(1−)	+21 (3)	(v)	+ 9.6
		9.75	6.5	−0.1		+ 8 (6)	+ 6 (10)		(v)		+ 7.
		16.70	6.5	0.0		+12 (3)	+ 8 (5)				+10.
	Oct.	11.64	6.4	0.0		+ 8 (2)	+ 6 (3)				+ 7.
										Mean,	+ 9.4

BRIGHT-LINE RADIAL VELOCITY

Sept. 9.68	4007.35 Å	+ 26 km.
9.72	4007.13	+ 10

The assumed normal wave-length of 4007.0 was deduced from Stebbins' measures of the line in the spectrum of *o* Ceti.

The radial velocities from the bright lines are collected in Table II. In no instance is the motion thought to be variable. The residual velocities are computed on the assumption that the sun is approaching the point $\alpha = 270°\ 0'$, $\delta = +28°\ 0'$, with a speed of 20.0 km. per second. The mean taken without regard to sign is 36.5 km. The algebraic mean is − 21.4 km. It is noteworthy, although possibly only a coincidence, that this value has the same sign and about the same magnitude as the average divergence between bright and dark line velocities to be discussed later in this paper.

TABLE II. RADIAL VELOCITIES FROM BRIGHT LINES.

	Star.	Observed Velocity.	Residual Velocity.	Remarks.
001755	T Cassiopeiae	— 27 km.	— 20 km.	
001838	R Andromedæ	— 36	— 31	
012502	R Piscium	— 59	— 65	
021024	R Arietis	+101	+ 96	
021143	W Andromedæ	— 44	— 44	
021043	*o* Ceti	+ 52	+ 42	
050953	R Aurigæ	— 9	— 12	
061702	V Monocerotis	+ 16	— 2	
065355	R Lyncis	+ 11	+ 9	
071044	L_2 Puppis	+ 51	+ 32	D. O. Mills Expedition.
084803	S Hydræ	+ 77	+ 65	
085008	T Hydræ	— 12	— 26	
093934	R Leonis Minoris	— 6	— 9	
094211	R Leonis	0	— 8	
103769	R Ursæ Majoris	+ 23	+ 30	
121418	R Corvi	— 34	— 36	
123160	T Ursæ Majoris	—107	— 98	
123307	R Virginis	— 35	— 31	
123961	S Ursæ Majoris	— 1	+ 9	
132422	R Hydræ	— 26	— 24	
134440	R Canum Venaticorum	— 24	— 12	
142539	V Bootis	— 41	— 27	
143227	R Bootis	— 57	— 43	
151731	S Coronæ	— 22	— 6	
154615	R Serpentis	+ 8	+ 25	
162119	U Herculis	— 40	— 22	
163137	W Herculis	— 59	— 40	
164715	S Herculis	— 21	— 5	
170215	R Ophiuchi	— 59	— 45	
171401	Z Ophiuchi	— 93	— 75	
180531	T Herculis	—130	—110	
181136	W Lyræ	—186	—166	
183308	X Ophiuchi	— 86	— 67	
193311	RT Aquilæ	— 54	— 36	
193449	R Cygni	— 34	— 15	Wright
194048	RT Cygni	—127	—109	
194632	χ Cygni	— 17	+ 1	
205923	R Vulpeculæ	— 17	— 2	
210868	T Cephei	— 30	— 17	
213244*	W Cygni	— 26	— 12	
231425	W Pegasi	— 35	— 27	
231508	S Pegasi	— 7	— 2	
235350	R Cassiopeiæ	+ 9	+ 17	
	Algebraic Mean		— 21.4	
	Arithmetic Mean		36.5	

* Plates by R. H. Curtiss at Lick Observatory, measured by Merrill.

If each of the residual velocities be corrected by $+17$ km., there will be 21 positive, 1 zero, and 21 negative values. The arithmetic mean, 32.1 km., will then be a minimum. This would not be reduced by using the dark line velocities where known. We may then take the average value of the residual motion as derived from the present data as 32 km., making them apparently the swiftest of any class of stars so far investigated.

There are strong indications, however, that the observed velocities are not wholly at random but are affected by a motion systematic with regard to the extensive group of stars from which the solar motion has been determined. The correction to remove the velocity due to the sun's motion is $V_{\odot} \cos d$, where $V_{\odot}$ is the sun's speed, and d is the angle between the star and the solar apex. The residual velocities are collected in Table III with respect to this correction, where $V_{\odot}$ is taken as 20.0 km. This is done in order that the effect of assuming other values of the sun's speed may be easily estimated. In view of the small number of stars, their large individual motions, and their lack of uniform distribution over the sky, it has not been considered advisable to make a solution for the sun's motion. It is obvious, however, from Table III, that if the apex be assumed as $\alpha = 270° 0'$, $\delta = +28° 0'$, a velocity much higher than 20.0 km. would result, or in other words, these 43 stars seem to have a systematic motion in the general direction of the solar ant-apex.

TABLE III. RESIDUAL VELOCITIES FROM BRIGHT LINES BY ZONES.

20 cos d	AVERAGE RESIDUAL VELOCITY.	NO. OF STARS.
-20 to -10	$+22$	5
-9 to -5	$+8$	3
-4 to 0	-16	5
$+1$ to $+5$	-22	4
$+6$ to $+10$	-15	6
$+11$ to $+15$	-23	7
$+16$ to $+20$	-48	13

Table IV exhibits the relation between residual velocity and maximum magnitude as taken from *Annals H. C. O., 56,* pp. 197 ff. It indicates that the fainter stars are moving with considerably greater rapidity than the brighter ones. Since only a few of these stars are as bright, even at maximum, as the stars of other spectral classes which have entered into average radial velocities, it remains to be seen whether the apparently great radial velocities of stars of Class Md should be considered as an effect of spectral class or of magnitude.

TABLE IV. AVERAGE RESIDUAL VELOCITY FROM BRIGHT LINES, AND MAXIMUM MAGNITUDE.

MAGNITUDE AT MAXIMUM.	AVERAGE RESIDUAL VELOCITY.	NO. OF STARS.
0.0 to 5.0	20 km.	6
5.1 to 6.5	34	11
6.6 to 7.2	35	13
7.3 to 8.0	48	13

With very few exceptions, the bright lines observed in these stars by the writer have appeared monochromatic with the dispersion used, i. e., no wider than titanium comparison lines of the same intensity. Other observers have frequently (but not always) found them narrow with three prism dispersion. A central reversal has, I believe, never been noted. These facts together with the rapid changes in intensity, which they undergo, have given the writer the impression that the emission lines are, in general, high level phenomena.

When a hydrogen tube is made luminous in the laboratory by the passage of an electric discharge, the spectral lines decrease in strength in the order $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, etc. This is also the order of the hydrogen emission lines of stars of Class B. But in stars of Class Md, as is well known, it is not always so. Table V indicates the nature and the extent of the deviations.

TABLE V. INTENSITIES OF BRIGHT LINES.

TITANIUM BANDS	$H\beta : H\gamma$	$H\delta : H\gamma$	$H\delta : H\beta$	NO. OF STARS.
Not seen	1.7	0.4	0.2	4
Not prominent	0.7	1.0	1.5	6
Strong	0.3	1.2	4.6	18
Very strong	0.2	2.3	13.4	8

In many or all stars the relative intensities are variable, hence, an attempt has been made to estimate the average, or characteristic ratio for use in Table V. Published descriptions, the Ann Arbor spectrograms, and notes made by the writer at Cambridge on spectra in the collection of the Harvard College Observatory, have been used. When one of the three lines, Hβ, Hγ, Hδ, was not seen at all, it was assigned the greatest intensity which the photographic conditions seemed to warrant. This process could scarcely accentuate the peculiarities observed in Table V since, aside from errors in estimating, the effect would be to smooth out differences between the lines. The departure from the laboratory (normal?) relative intensities seems to proceed in close accord with the strength of the absorption bands of titanium oxide. One cannot be sure whether the titanium oxide is directly responsible, or whether the two effects exist in parallel from a common cause.

It is suggested that the numerical ratios of intensity, Hδ : Hγ, and Hδ : Hβ might be used as criteria for the subdivision of the spectral Class Md.

According to the writer's experience 3905 Å (Si?) is in general the most prominent emission line not in the hydrogen series, occurring in Md spectra. An emission line at 4202 Å, presumably due to iron, as well as unidentified emission lines at 4138.9 Å and 4007.1 Å, has been measured in a few stars. All four of these lines had been previously observed in the spectrum of *o* Ceti.

The miscellaneous bright lines in spectra of Class Md may prove of great importance not only in theories of long-period variation, but in widely different connections. Observers should not fail to note them whenever possible.

ABSORPTION LINES

Due to underexposure, the absorption spectrum is measurable on only a small proportion of the Ann Arbor spectrograms of these stars.

In measuring the plates no attempt was made to include all the lines, but settings were made only on those which seemed capable of yielding fairly reliable velocities. The normal wavelengths, contained in Table VI, were gathered from various low-dispersion measures of solar and late type stars, and from Stebbins' determinations in *o* Ceti, only one or two values being taken from Rowland. In Table VI

o = Stebbins' measures of *o* Ceti,
R = Rowland,
L = Miscellaneous one-prism measures of stars of Classes G, K, M.

TABLE VI.
ASSUMED NORMAL WAVE-LENGTHS OF ABSORPTION LINES IN CLASS Md.

Å.		Å.	
3982.3	o	4272.0	o L
3998.84	o	4274.96	R Cr
4005.4	L Fe	4289.84	o L
4031.3	o	4303.1	o
4063.78	L Fe	4314.6	L
4071.7	o L	4319.1	o L
4091.42	o L	4326.00	o L Fe
4092.7	o L	4330.2	o
4096.18	o	4347.16	o
4109.44	o	4368.4	L
4112.07	o	4375.4	L
4123.75	o	4379.35	o
4134.4	o	4384.63	o L Fe
4140.0	o	4389.75	o
4149.8	o	4395.3	o L
4152.5	o	4404.92	L
4160.0	o	4408.3	o
4164.9	o	4415.25	L Fe
4187.25	o	4482.0	L
4190.9	o	4489.8	L
4215.95	L	4522.94	Ti
4226.90	R Ca	4535.8	o
4250.7	o L	4738.45	o
4254.50	R Cr		

021430. o CETI.

Measures of seven three-prism plates in 1897-98 by Campbell and Wright gave a mean velocity of + 62.3 km., for the absorption lines, (*Ap. J., 9*, 31, 1899). One-prism plates taken in 1902 yielded a mean velocity of + 66 km. from six absorption lines as measured by Stebbins, (*Lick Observatory Bulletin, 2*, 93, 1902).

Measures of two three-prism plates in December, 1906, by Plaskett, gave a mean velocity of + 65.4 km. for the absorption lines, (*Jour. R. A. S. Canada, 1*, 48, 1907).

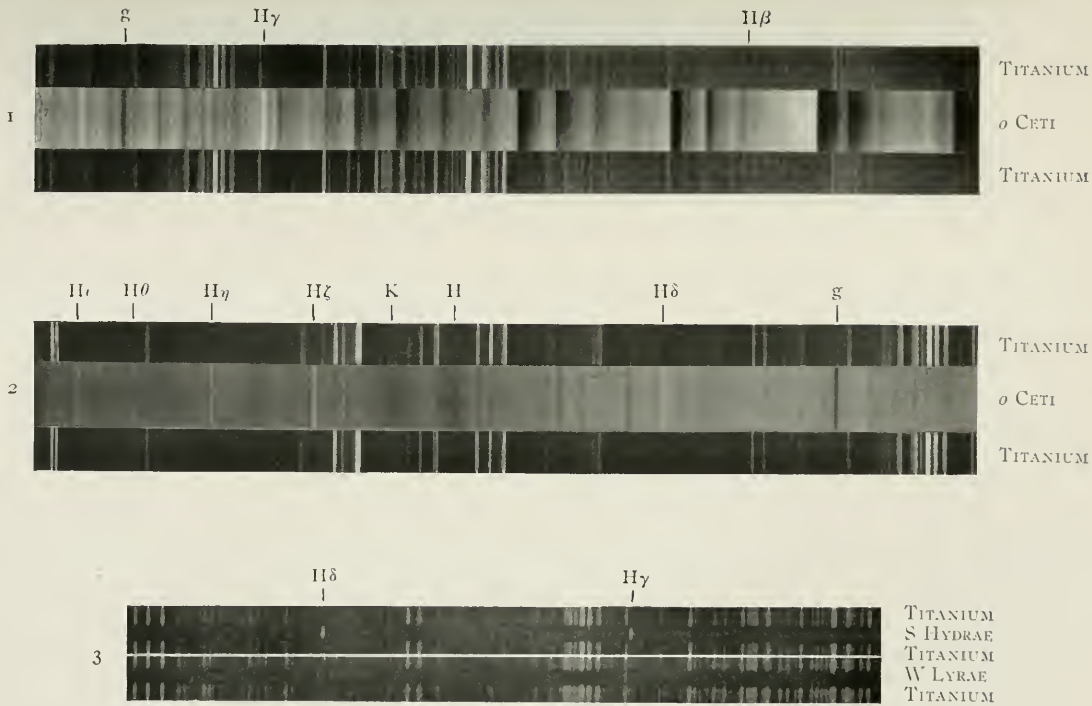

Plate F. 1 and 2. Overlapping Sections of the Spectrum of the Long Period Variable Star, Omicron Ceti, with Titanium Spark Comparison, 1915, January 29

3. Spectra of the Long Period Variable Stars, S Hydrae and W Lyrae, Showing Opposite Displacements of Hδ and Hγ Emission Lines
Dates: S Hydrae, 1915, March 26; W Lyrae, 1914, July 9

ANN ARBOR OBSERVATIONS.

G. M. T. 1914 DEC. 25.57.		1915 JAN. 29.55.		1915 NOV. 12.66.	
PLATE WAVE-LENGTH.	RADIAL VELOCITY.	PLATE WAVE-LENGTH	RADIAL VELOCITY.	PLATE WAVE-LENGTH.	RADIAL VELOCITY.
3887.74		4000.04	+ 90 km.	4064.62	
3891.87		4032.13	+ 62	4072.88	+ 87 km.
3983.49	+ 90 km.	4056.48		4078.85	
3990.82	+ 74	4065.14		4097.19	+ 74
4006.72	+ 99	4073.15	+117	4110.66	+ 89
4032.06	+ 57	4078.99		4112.93	+ 63
4065.13		4097.34	+ 85	4192.12	+ 88
		4125.36	+117	4216.70	+ 53
4079.62		4161.24	+ 90	4251.68	+ 69
4097.72	+113	4217.03	+ 77	4255.82	+ 93
4125.16	+102	4228.18	+ 91	4326.97	+ 67
4228.32	+101	4255.88	+ 97	4385.50	+ 59
4255.80	+ 92	4327.33	+ 93	4390.64	+ 61
4273.33	+ 93	4385.77	+ 77	4572.69	+ 58
4276.34	+ 97	4396.53	+ 84	4577.49	
4348.58	+ 98	4406.30	+ 94	4739.68	+ 78
4385.77	+ 77	4409.82	+104		
4396.74	+ 98	4740.03	+100		
4409.80	+102				
4739.66	+ 77				
Mean	+ 92.0		+ 92.7		+ 72.2
To sun	— 26.1		— 29.0		— 9.9
Obs. V.	+ 65.9		+ 63.7		+ 62.3

Mean velocity from absorption lines (Ann Arbor Observations) + 63.9 km.

065355. R LYNCIS.

PLATE WAVE-LENGTHS.

G. M. T. 1915 FEB. 28.70.	1915 FEB. 28.74 UNDEREXPOSED.
4524.03 Å	4607.26 Å
4586.70	4699.01
4621.89	4753.75
4634.61	
4723.93	
4806.62	
4816.76	
To sun — 22 km.	

There is a broad absorption band containing narrower absorption lines, having its center about 4645-50 Å. The absorption spectrum differs greatly from that of the other stars of Class Md, not resembling them in this respect much more than it does stars of Class N.

The spectrum bears a considerable resemblance to that of R Cygni, as observed by Wright. See remarks under that star.

071044. L_2 PUPPIS.

Observations by D. O. Mills Expedition, kindly communicated by Director Campbell, as follows:

1911. TWO-PRISM PLATES, ABSORPTION LINES.

	+ 51.6 km.
	+ 53.2
	+ 53.0
Mean........	+ 52.6

1914, ONE-PRISM PLATES, ABSORPTION LINES.

	+ 53.5
	+ 55.5
Mean........	+ 54.5
Mean of all..	+ 53.1

Remark by Campbell. "This star seems to be an exception in that absorption and radiation lines give approximately equal velocities."

093934. R LEONIS MINORIS.

G. M. T. 1915 FEB. 19. 83.

PLATE WAVE-LENGTH	RADIAL VELOCITY
4124.05	+ 22 km.
4290.41	+ 40
Mean	+ 31 ±
To sun	− 7
Obs. Velocity	+ 24 ±

094211. R LEONIS.

Measure by Lick Observatory, kindly communicated by Director Campbell: one three-prism plate, absorption lines give + 11 km.

ANN ARBOR OBSERVATIONS.

G. M. T. 1914 FEB. 28.78.		1914 MARCH 14.74.	
PLATE WAVE-LENGTH.	RADIAL VELOCITY.	PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4124.34	+ 43 km.	4124.27	+ 38 km.
4255.04	+ 38	4254.64	+ 10 p.
4290.27	+ 30	4290.18	+ 24
4303.61	+ 35		
4326.55	+ 38	4326.74	+ 51 p.
4377.22			
4380.07	+ 49		
4385.05	+ 29		
4389.57		4390.48	+ 33 p.
4662.11			
4738.60	+ 10 p.	4739.30	+ 54 p.
4943.40			
Mean	+ 35.6		+ 37.3
To sun	— 8.0		— 14.7
Obs. V.	+ 27.6		+ 22.6

Mean velocity from absorption lines (Ann Arbor Observations) + 25 km.

103769. R URSAE MAJORIS.

G. M. T. 1915 FEB. 19.83.		1915. FEB. 26.74.	
PLATE WAVE-LENGTH.	RADIAL VELOCITY.	PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4124.46	+ 51 km.	4227.43	+ 38 km.
4216.72	+ 38	4315.38	+ 54
4384.93	+ 20 p.	4326.79	+ 55
4396.10	+ 55	4384.72	+ 6 p.
4571.73		4405.59	+ 45
4607.24		4408.79	+ 33
4739.94		4536.31	+ 34
Mean	+ 46.5		+ 40.3
To sun	— 7.8		— 9.5
Obs. Vel.	+ 38		+ 31

Mean velocity from absorption lines, + 34 km.

132422. R HYDRAE.

Observations by Lick Observatory, kindly communicated by Director Campbell: two three-prism plates give for the absorption lines —3 km.

ANN ARBOR OBSERVATIONS.

G. M. T. 1915 MAY 30.61.

PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4326.62	+ 43 km.
4330.34	+ 10
4380.04	+ 47 p.
4384.59	— 3 p.
4395.53	+ 16
4489.83	+ 2 p.
4536.12	+ 21 p.
4739.06	+ 39
Mean	+ 24
To sun	— 18
Obs. V.	+ 6

142539. V BOOTIS.

G. M. T. 1915 FEB. 28.90.

PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4164.09	— 58 km.
4226.47	— 31 p.
4254.00	— 35
4325.60	— 24
4383.67	— 66
4481.39	— 41
4534.85	— 63
4570.91 p.	
4737.87	— 37 p.
Mean	— 44.4
To sun	+ 11.5
Obs. V.	— 33

143227. R BOOTIS.

G. M. T. 1915 FEB. 28.81.

PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4122.58	— 85 km.
4288.77	— 75 p.
4318.34	— 53
4320.36	
4346.44	— 50
4387.63	— 68
4394.60	— 48
4404.09	— 56
4414.51	— 50
Mean	— 60.6
To sun	+ 17.8
Obs. V.	— 43

151731. S CORONAE.

G. M. T. 1915 FEB. 26.93.		1915 MARCH 7.30.	
PLATE WAVE-LENGTH.	RADIAL VELOCITY.	PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4090.27	— 11 km.	4139.72	— 20 km.
4092.64	— 4	4226.66	— 17
4123.72	— 2	4254.39	— 8
4139.59	— 30	4326.17	+ 12
4187.05	— 14	4384.21	— 29
4226.74	— 11	4389.67	— 5
4254.26	— 17	4394.85	— 31
4271.69	— 22	4404.84	— 5
4274.77	— 13	4408.06	— 16
4314.32	— 19	4571.36	
4325.87	— 9	4737.70	— 48
4384.00	— 43	4842.93	
4408.21	— 6		
4535.57	— 15		
4737.79	— 42		
Mean	— 17.2		— 16.7
To sun	+ 17.1		+ 15.3
Obs. V.	— 0.1		— 1.4

Mean velocity from absorption lines, — 0.7 km.

154615. R SERPENTIS.

G. M. T. 1914 APR. 11.88.

PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4216.33	+ 27 km.
4254.53	+ 2
4227.06	+ 11
4271.90 p.	
4314.91	+ 22
4326.40	+ 28
4368.85	+ 31
4384.63	0 p.
4390.12	+ 25 p.
4405.14	+ 14
4523.40	+ 30
4571.58 p.	
4737.97 p.	
Mean	+ 19.8
To sun	+ 12.0
Obs. V.	+ 32

193449. R CYGNI.

Observations by Wright at Lick Observatory, *Mon. Not. R. A. S.*, *72*, 548, 1912.

The spectrum as observed by Wright in December, 1911, and January, 1912, is similar to that of R Lyncis as observed at Ann Arbor in February, 1915, in the following respects: general appearance; relative intensities of bright hydrogen lines; broad absorption band with center about 4645 Å; several prominent absorption lines as shown in the following table, which gives measured wave-lengths, not reduced for radial velocity.

	R CYGNI	R LYNCIS	DIFFERENCE.	
			Å	KM.
Em.	4101.4 Å	4101.8 Å	0.4	29
Em.	4340.2	4340.9	0.7	62
Abs.	4606.2	4606.9	0.7	46
Abs.	4620.9	4621.6	0.7	45
Abs.	4633.7	4634.3	0.6	39
Em.	4860.7	4861.7	1.0	62

The differences for various lines are fairly consistent, and are probably due to differences in radial motion, and errors of observation.

Mrs. Fleming classified the spectrum of R Cygni on different plates as Md1, Md2, Na, Pec.

194632. χ CYGNI.

Eberhard (*Ap. J. 18*, 198, 1903) records radial velocities from the dark lines as follows:

	G. M. T.		
1901	Aug.	9.38	+2.5 km.
		10.39	+2.3
1902	Sept.	24.31	−1.3
		26.33	−3.3
Mean			+0.1

213244. W CYGNI.

The following are measures made by the writer, of plates taken by Professor R. H. Curtiss at Lick Observatory in 1903, with Spectrograph I (*Lick Bulletin*, *3*, 41, 1904). I am indebted to Professor R. H. Curtiss and to Director Campbell for the opportunity of using them. The measures were reduced by means of the table found in *Lick Bulletin*, *3*, 29, 1904.

DATE: 1903 AUG. 3.		1903 AUG. 7.		1903 AUG. 26.		1903 SEPT. 13.	
TABULAR WAVE-LENGTH.	RADIAL VELOCITY.	TABULAR WAVE-LENGTH.	RADIAL VELOCITY.	TABULAR WAVE-LENGTH.	RADIAL VELOCITY.	TABULAR WAVE-LENGTH.	RADIAL VELOCITY.
4063.7	−13 p.	4384.5	−29	4118.8	−54	4024.8	−58
4132.5	−33	4404.9	−29	4187.6	−25	4046.0	−35
4216.0	−24			4191.7	−45	4092.8	−28
4227.0	−28			4384.5	−25	4118.8	−32
4275.1	−30			4395.0	−27	4128.0	−16
4384.5	−52 p.			4404.9	− 2 p.	4134.5	−43
						4187.6	−12
						4395.0	−52
				4571.8	−19	4571.8	−44
Mean	−29.3		−29		−30.3		−35.0
To sun	+10.3		+ 9		+ 4.5		− 0.7
Obs. V.	−19		−20		−26		−36

Mean velocity from absorption lines, −27 km. The range is not significant.

235350. R CASSIOPEIAE.

G. M. T. 1914 SEPT. 9.68.		1914 SEPT. 9.72.	
PLATE WAVE-LENGTH.	RADIAL VELOCITY.	PLATE WAVE-LENGTH.	RADIAL VELOCITY.
4030.86		4030.87	
4064.10	+ 24 km.	4072.04	+ 25 km.
4078.03		4124.19	+ 32
4143.57 p.		4134.59	+ 14
4191.59	+ 49	4139.99	0
4194.74		4150.20	+ 29
4216.15	+ 14	4153.17	+ 48
4227.36	+ 33	4191.31	+ 29
4251.25	+ 39	4216.11	+ 11
4254.64	+ 10	4227.19	+ 21
4275.26	+ 21 p.	4254.79	+ 13
4314.84	+ 17	4314.70	+ 7 p.
4326.31	+ 22	4326.57	+ 40
4375.75	+ 24	4376.04	+ 44
4384.70	+ 5	4384.55	− 5
4395.27 p.		4405.16	+ 16
4405.33	+ 28	4408.79	+ 33
4408.62	+ 22	4571.60	
4571.70		4738.30 p.	
4738.68	+ 13		
Mean	+ 22.9		+ 22.3
To sun	+ 12.7		+ 12.6
Obs. V	+ 35.6		+ 34.9

Mean velocity from absorption lines, + 35 km.

The values in the last column of Table VII are not in all cases the exact differences of the numbers in the preceding columns because more weight was given to those Ann Arbor plates upon which both sets of lines were measured, and the values of other observers were taken into account where available.

The relative displacement of the bright and dark lines appears characteristic of the stars of Class Md. The two stars which do not show it, L_2 Puppis and W Cygni, are differentiated from the others in that they have short periods and small magnitude ranges. The presence of the bright lines and their peculiarities seem to depend upon the activity of the star but not to represent the direct cause of it.

TABLE VII. RADIAL VELOCITIES FROM BOTH BRIGHT AND DARK LINES.

STAR.		DARK LINES.	BRIGHT LINES.	ADOPTED DARK MINUS BRIGHT.
021403	o Ceti	+ 64 km.	+ 52 km.	+ 14 km.
071044	L_2 Puppis	+ 53	+ 51	+ 2
093934	R Leonis Minoris	+ 24 ±	− 6	+ 29 ±
094211	R Leonis	+ 25	0	+ 24
103769	R Ursæ Majoris	+ 34	+ 23	+ 12
132422	R Hydræ	+ 6	− 26	+ 26
142539	V Bootis	− 33	− 41	+ 11
143227	R Bootis	− 43	− 57	+ 13
151731	S Coronæ	− 1	− 22	+ 21
154615	R Serpentis	+ 32	+ 8	+ 23
194632	χ Cygni	0	− 17	+ 20
213244	W Cygni	− 27	− 26	+ 1
235350	R Cassiopeiæ	+ 35	+ 9	+ 26

GENERAL REMARKS ON LONG-PERIOD VARIATION—CLASS Md.

The spectra and light-curves of these stars are so essentially similar to one another that we may confidently presuppose the same general explanation in all cases; and since no star shows variation in radial motion, or the characteristics of eclipsing systems, we have no evidence that the light changes are due to the influence of a companion star. It is true, however, that only a very few stars have had their radial motions measured at times other than near maximum, but it does not seem probable that many, if indeed any, will prove to be spectroscopic binaries.

In view of the lack of spectroscopic observations which trace the spectral variations through the minimum phase, the writer offers the following "Tentative outline of spectral variations" merely as a basis for amplification and, if need be, correction. It is not a description of the history of any particular star (which would be extremely valuable) but depends upon miscellaneous observations from various sources.

TENTATIVE OUTLINE OF SPECTRAL VARIATIONS—CLASS Md.

1. Minimum. Absorption spectrum similar to that of Class M.

2. Rise to Maximum. After the star has risen from one to three magnitudes (perhaps one-third or one-half the whole ascent) the bright hydrogen lines appear, $H\delta$ appearing first, followed by $H\gamma$, $H\zeta$ and others, and possibly $H\beta$ and $H\alpha$.

3. Maximum. The bright hydrogen lines are very strong and are displaced to the violet relatively to the absorption lines by the equivalent of about 20 km. The series often extends to $H\iota$ (3771 Å) but seems to end there abruptly. $H\epsilon$ is conspicuous by its absence or decided weakness.

4. Decline to Minimum. The spectrum remains nearly the same as the star drops one or two magnitudes, the bright hydrogen lines fading slowly, and other bright lines, notably 3905 Å Si?. etc., become relatively stronger. This continues until minimum except that the secondary bright lines become faint at or just before, minimum.

HYPOTHESES TO EXPLAIN VARIABILITY.

Comparison of the curves of long-period variables with the graph of solar spottedness has led to the idea that there may be an analogy between the two phenomena.[12] The dimming of the stellar surface by spots would probably not be considered sufficient to account for the great variations observed, and in fact the analogy points in the opposite direction, namely, that stellar light-maximum corresponds to spot maximum on the sun. Observations of the solar constant seem to show that the sun radiates more heat at spot maximum than at other times, which appears consistent with its greater internal activity. Thus in the star there may be recurrent periods of activity which greatly increase its brightness and alter details in its spectrum. However, the corresponding effects observed upon the sun are so exceedingly slight in comparison that the use of them to account for stellar variability of this type is a long and a precarious extrapolation.

The so-called "geyser theory" does not differ very essentially from the above, except in presupposing the formation of a viscous, and perhaps even solid, crust at minimum which is finally broken through by the gradually increasing pressure of the gases imprisoned beneath it.[13] The resulting uprush of gas is suggested to account for the relative velocity of approach yielded by the emission lines. It is hard to see, however, how it could be sustained at a constant value over as long an interval as the observations have shown it. And it is difficult to understand why large quantities of hydrogen should become imprisoned under a heavy crust.

When we remember the great dimensions of these stars and the large amounts of energy concerned the enormous changes of brightness which they undergo in the course of a few months are perplexing occurrences. The spectral changes seem small in comparison with the variations in total light. In view of these considerations, as well as others, it might be well to keep in mind the possibility that a star of this class may not actually change its brightness so greatly, but that at time of minimum a screen is interposed between it and the earth, presumably in the immediate vicinity of the star. It is suggested that this might be composed of condensing gases, possibly calcium vapor, in the upper atmosphere of the star. Calcium exists at high levels in the solar, and in many stellar atmospheres, and especially in these stars if we admit that the hydrogen line $H\epsilon$ is blotted from the spectrum by the absorption of calcium H. The cloud formed by condensation would conserve the heat radiated from the photosphere to space so that the temperature of the materials immediately above the photosphere would increase until the overlying veil is again vaporized and the star shines out brightly. It is easy to conceive that these phenomena would be periodic and would cause variations in the spectrum, particularly in chromospheric emission. Possibly electrical effects having their origin in the evaporation of the cloud are effective in stimulating the hydrogen and other gaseous emission. If so the source would be at a high level, which seems to accord with observation especially if we assume that the relative displacement of bright and dark lines is due to pressure.

The tentative idea submitted in the above paragraph might be conveniently styled the veil theory. The writer proposes that it be considered as an alternative working hypothesis.

Ann Arbor, 1916, January 7.

[12] Clerke, *Problems in Astrophysics*, p. 362.

[13] Campbell, *Stellar Motions*, p. 303.

A SPECTRUM OF THE P CYGNI TYPE

By PAUL W. MERRILL

INTRODUCTION.

One of the first generalizations drawn from extensive observations of stellar spectra was the recognition of a single sequence in which there was a place for nearly every star examined. As a matter of convenience certain definitely characterized types were chosen as a framework for classification first by Secchi, later by Vogel, and Lockyer, and lastly and on the most complete basis by investigators at the Harvard College Observatory. In a manner somewhat, but not wholly, arbitrary the remaining objects are said to be intermediate, or in case they do not fit into the scheme at all, anomalous. The Harvard Classification of Stellar Spectra, using the letters B, A, F, etc., to designate the divisions, is almost universally adopted in this country, and is largely used in Europe. Corresponding to a wider range of observation and increased knowledge the system has been slowly extended to include more and more objects, for some of which no provision had been made at first, so that now there remain outstanding only a few isolated specimens or small groups of intractable objects. The past few years have witnessed considerable success in establishing connections and relationships between these and the better understood types of the regular classification. That this field is considered an important one is shown by the large amount of labor spent in cultivating it, and its fertility is evidenced in results obtained.

Occupying a prominent position among these outstanding objects is the typical spectrum of a nova or new star. The spectrum of such a star usually changes rapidly, and very curiously the later epochs seem to include two other remarkable types of spectra, namely those known as nebular, and Wolf-Rayet, or Class O. There seems to be a fairly direct sequence connecting Class O spectra with Class B, which is usually accounted the first division in the main progression. And recently Wright has shown in several instances that a planetary nebula has a Wolf-Rayet star as a nucleus, and infers that in general planetary nebulae are condensing to form Wolf-Rayet stars. In this connection it is interesting to note that in the later history of the changes of a nova spectrum a period characterized as nebular is followed by one which Adams has shown to possess strong resemblances to Wolf-Rayet spectra.

After a sudden rise from obscurity a nova usually fades again in a few weeks or months to a low magnitude, but there is one notable exception to this rule. In 1600 a star appeared near the intersection of the arms of the great cross of the constellation Cygnus. As usual there were marked fluctuations in brightness but in this object they were measured by years rather than by days and weeks. They continued for about three-quarters of a century leaving the star at the fifth magnitude where it has remained ever since, well visible to the unaided eye. Moreover the spectrum retains certain characteristics associated with the earlier stages of typical novae. It was classified at Harvard as "B1 with hydrogen lines bright".

While this star, known as P Cygni,[1] may eventually prove valuable in the study of nebulae and Wolf-Rayet stars, it has an immediate application in the interpretation of the complicated spectra of novae near maximum. In 1913 there occurred certain small but rather striking changes[2] in the hydrogen lines of P Cygni which related that star still more closely to typical novae through a peculiar feature of the spectrum exhibited by both. The study of the star's spectrum may be of value in its application to the more general problem of novae both in general and in detail. For instance we must admit that the conditions causing the peculiar distribution of the light in many of the lines can under some conditions exist for a long period of years without much change; and we may be furnished the opportunity in P Cygni of viewing the complete

[1] *Harvard Annals, 28*, 101, 1895; *Astrophysical Journal, 35*, 286, 1912; *Popular Astronomy, 22*, 133, 1914.

[2] *Lick Observatory Bulletin, 8*, 24, 1913.

cycle of nova history leisurely and much more thoroughly than when it is hurried through in a few weeks, or when the star fades to a magnitude at which it is difficult to observe. And, on the other side, Wright's probable identification of nitrogen in the spectrum of Nova Lacertae[3] is rendered more certain by the fact that nitrogen lines are undoubtedly prominent in the spectrum of P Cygni.

For the reasons outlined above the announcement by Miss Cannon in *Harvard Annals, 76*, No. 3, p. 31, of ten additional "Spectra of the P Cygni Type" is of much interest. Since the Harvard plates of these faint stars are of small dispersion and without comparison spectra it was impossible to decide from them just how far the resemblance to P Cygni extended. A detailed comparison of these spectra with P Cygni and with each other may prove of considerable value in the interpretation of these curious phenomena, and may help remove them from their apparent isolation by bringing to light some connections with more familiar types.

A single one of these ten stars is available for examination at northern observatories. Five one-prism spectrograms of this object, DM. + 11° 4673, have been obtained at Ann Arbor, and serve as the basis for the discussion which follows.

DM. + 11° 4673.

R.A. 1900 $21^h 46.^m2$; Decl. 1900 + 12° 9′; Mag. 7.7.

JOURNAL OF OBSERVATIONS.

PLATE NO.	DATE, G. M. T.	DURATION OF EXPOSURE.	OBSERVER.
3228A	1915 May 21.82	$2^h 20^m$	Merrill.
3259B	June 13.78	2 10	Merrill.
3332A	July 23.78	3 30	Merrill.
3340B	Aug. 6.81	4 4	Merrill.
3368A	Nov. 12.54	3 0	Dawson. Merrill.

THE HYDROGEN LINES.

The only conspicuous lines in the spectrum are those due to hydrogen. As in P Cygni they consist of strong bright portions superposed on the continuous spectrum, apparently in their normal positions except for Doppler effects, with absorption borders on their more refrangible edges. In DM. + 11° 4673 the absorption borders are much less intense, and in some cases might be overlooked unless the exposure were exactly correct to show them most distinctly. Bright Hβ, Hγ, Hδ were first observed by Mrs. Fleming,[4] more[5] than 22 years ago, while bright Hα was seen shortly after by Campbell. As is usual in stars of early types the bright hydrogen series decreases in strength toward the shorter wave-lengths, but in this star the accompanying dark lines show no decided increase. Both bright and dark lines are narrow. Settings on the bright portions give consistent velocity results while the displacements of the dark lines are not to be interpreted as due to radial motion.

In Table I the correction for the solar motion is + 11.5 km., making the residual velocity + 27.5 km. which is rather high for a star of Class B.

In Table II are given the measured displacements of the dark hydrogen lines with respect to their bright components.

The displacement decreases with wave-length. The slight discrepancy shown by Hϵ is probably to be explained by the influence of the absorption line H, of calcium, since K is visible as a dark line. The values are decidedly less than the corresponding ones for P Cygni. Both bright and dark portions are narrower and weaker than in P Cygni. Whatever the physical conditions may be which cause the peculiar appearance of these lines, they are evidently less intense in the fainter star.

In one or two instances a narrow, weak, dark line is seen on the redward edge of a bright hydrogen line.

BRIGHT LINES NOT DUE TO HYDROGEN

In addition to the hydrogen lines there are many fainter emission lines largely of metallic origin. There are also numerous absorption lines, a condition giving rise to a difficulty in interpretation well known to those who have studied a complicated spectrum of this kind. The difficulty

[3] *Lick Observatory Bulletin, 6*, 95, 1911.

[4] *Astronomy and Astrophysics, 13*, 502, 1894.

[5] *Astrophysical Journal, 2*, 180, 1895.

TABLE I. VELOCITIES FROM BRIGHT HYDROGEN LINES.

KILOMETERS PER SECOND.

PLATE.	Hβ	Hγ	Hδ	Hε	Hζ	Hη	Hθ	MEAN.
3228A	+ 18	+ 7	+ 19					+ 15
3259B	+ 6	+ 13	+ 16	+ 17				+ 13.2
3332A	+ 23	+ 16	+ 18	+ 23	+ 20	+ 19		+ 19.9
3340B	+ 18	+ 7	+ 17	+ 19	+ 20	(+ 36)	(+ 10)	+ 16.5
3368A	+ 14	+ 15	+ 8	+ 22	+ 19	+ 10	(+ 8)	+ 14.6
Mean	+ 15.9	+ 11.8	+ 15.7	+ 20.5	+ 19.6	+ 19	(+ 9)	+ 16.0

TABLE II. BRIGHT MINUS DARK.

PLATE.	Hγ	Hδ	Hε	Hζ	Hη
3228A	1.45 Å	1.13 Å			
3259B	1.51	1.27	1.04 Å	1.2 Å	
3332A	1.63	1.22	1.34	1.05	
3340B	1.55	1.30	1.25	1.15	
3368A	1.83	1.25	1.42		1.01 Å
Mean	1.59 Å	1.23 Å	1.26 Å	1.12 Å	1.0 Å
	110 km.	90 km.	95 km.	86 km.	78 km.
P Cygni					
Frost[6]					
1-prism	2.73 Å	2.38 Å			
Merrill[7]					
3-prism	2.48 Å				

is enhanced in this spectrum by the general weakness of the lines except those of hydrogen, and by the fact that a single line is apt to have both bright and dark components, so that the true character of some of the poorer lines remains in doubt.

It is a striking fact that as regards the fainter emission lines DM. + 11° 4673 and P Cygni seem to have nothing at all in common. The P Cygni lines, almost wholly non-metallic, are not found in the fainter star. Several of the bright lines of DM. + 11° 4673 are accompanied by very weak absorption components, particularly 4244 Å, 4287 Å, 4352 Å, 4583 Å, and 4629 Å. Quite in contrast with P Cygni, the absorption border is seen about as frequently on the red as on the violet edge. The following table gives in the first column the measured wave-lengths of emission lines of the star under consideration. They have been reduced for the velocity measured on each plate from the bright lines of hydrogen. The displacements given in the third column are therefore relative. To obtain actual velocities with respect to the sun the hydrogen velocity +16.0 km. must be applied.

This star seems to occupy an intermediate position between P Cygni (and novae?) and those stars of Class B showing bright hydrogen lines such as γ Cassiopeiae and φ Persei. The lines of hydrogen show the characteristic structure of the P Cygni lines, though in a less marked degree, but this phenomena does not clearly extend to the other lines, although that is the case in P

[6] *Astrophysical Journal, 35*, 286, 1912.

[7] *Lick Observatory Bulletin, 8*, 24, 1913.

TABLE III. BRIGHT LINES.

DM. 11°4673.	SOLAR CHROMOSPHERE.		DISPLACEMENT.	NOTES.
				All lines observed as bright unless otherwise noted.
3855.9 Å	3856.40 Å	Fe, Si.	—41 km	β Lyræ 3853.76, 56.16, 62.73.
3905.3	3905.67	Si, Cr.	—33	Bright line near here in spectra of Class Md, Si?
4232.8	4233.40	Fe, Cr.	—45	β Lyræ 4233.33; γ Cassiop. 4233.60.
4244.0	Several near.			
4287.0	Several near.			
4351.7	4352.02	Cr, Mg.	—33	β Lyræ 4352.08; γ Cassiop. 4353.3; ϕ Persei 4353.0.
4358.6	Prob. blend of 2 or 3.			
4384.9	4383.70	Fe.	(+82)	Near He 4388.10 which is dark in DM. + 11°4673; γ Cassiop. 4384.25.
4549.2	4549.80	Ti, Fe, Co.	—35	β Lyræ 4549.64; ϕ Persei 4549.2.
4583.2	4584.04	Fe, V.	—51	β Lyræ 4584.02; γ Cassiop. 4583.76; ϕ Persei double, mean about 4583.8.
4628.7	4629.63	Ti, Fe, Co.	—58	β Lyræ 4629.79; γ Cassiop. 4629.3; ϕ Persei double, mean 4629.5.
Present	4924.14	Fe.		γ Cassiop. 4925.7; ϕ Persei 4924.

DOUBTFUL BRIGHT LINES.

Based on a single measure, or upon discordant measures.

3821.0	3820.57	Fe.		Close double, perhaps affected by dark He 3819.78.
3887.1	3886.46	Fe, La.		Real line? Near Hζ.
4121.6	4121.48	Co.		β Lyræ double, mean 4121.02; He 4120.97.
4177.6	4177.70	Y, Fe.		Double; γ Cassiop. double, mean 4177.4; ϕ Persei 4177.1.
4347.0	Several near.			
4416.5	Several near.			
4505.3				
4511.5				β Lyræ 4512.16 dark.
4555.2	Several near.			β Lyræ 4555.83 dark; ϕ Persei 4555.3.
4569.8				
Present	5018.61	Fe.		γ Cassiop. 5018.3; ϕ Persei 5018.4.

REFERENCES:

Solar Chromosphere, Mitchell, *Astrophysical Journal, 38*, 407, 1913.
β Lyræ, Curtiss, *Pub. Allegheny Observatory, 2*, 73, 1911.
γ Cassiopeiæ, Curtiss. This volume, p. 1.
ϕ Persei, Jordan, *Pub. Allegheny Observatory, 3*, 31, 1913.
Merrill, *Lick Obs. Bulletin, 7*, 166, 1913.
Compare also η Carinæ, Moore and Sanford, *Lick Obs. Bulletin, 8*, 55, 1914.

Cygni. As is evident from the last column of Table III the faint emission lines are those present in the spectra of ϕ Persei and stars of its class. If novae are caused by the plunge of a rapidly moving star into a nebula, is it possible that circumstances of a similar but less violent character are responsible for the bright lines of ϕ Persei and other stars of Class B? In any event the relations existing between these objects would seem to warrant close investigation.

Most of the bright lines of DM. + 11°4673 show a negative displacement of about 40 km.

with respect to the bright lines of hydrogen. They seem therefore to yield a velocity more nearly comparable with that from the dark lines, principally of helium. The observations of all lines except hydrogen are rather inaccurate, but the effect seems fairly definitely indicated. If real, the phenomenon is at variance with P Cygni as in that star bright lines of various elements give nearly consistent results. A similar effect of about the same magnitude has been observed in the spectrum of η Carinae.[8]

ABSORPTION LINES.

There are numerous dark lines which are not seen to have bright components. They show little contrast with the continuous spectrum and cannot be measured with great precision on the Seed 27 emulsion employed on account of the faintness of the star. Most of those which can be identified are due to helium.

TABLE IV. ABSORPTION LINES.

NORMAL WAVE-LENGTH.	VELOCITY.	NO. OF PLATES.
3933.82 K, Ca.	0 km. ±	3
4026.34 He	−15	3
4120.97 He	−14	1
4143.92 He	−2	3
4388.10 He	−11	5
4471.68 He	−19	2
4552.76 Si	−13	5

PLATE WAVE-LENGTH REDUCED TO SUN.	NOTES.
3995.2	β Lyræ 3995.17; P Cygni N; γ Cassiop. 3995.8.
4010.8 ±	He 4009.42.
4088.6	γ Cassiop. 4089.7; Si 4089.02; P Cygni.
4116.4	γ Cassiop. 4116.5; Si 4116.35; P Cygni.
4129.4	β Lyræ 4128.20; Si 4128.19.
4180.3	β Lyræ 4179.07.
4182.6	
4184.9	γ Cassiop. 4185.
4517.5	
4567.1	Near Si lines.
4573.4	Near Si lines.
4606.8	
4781.6	
(4922)	He 4922.10 present but not measured.

[8] *Lick Observatory Bulletin, 8,* 134, 1915.

The somewhat insecure relationship to P Cygni is reinforced by the behavior of the absorption lines which were measured for velocity. They yield a velocity algebraically less than that from the bright hydrogen lines; this is also true of the absorption lines of P Cygni.

SUMMARY.

1. The hydrogen lines of DM. + 11°4673, a star announced by Miss Cannon as "of the P Cygni type", are bright, with weak dark components on their more refrangible edges. The bright hydrogen lines agree in giving a radial velocity of +16.0 km.

2. Numerous emission lines of metallic origin are present in the spectrum. In several cases they are accompanied by very weak absorption borders which are seen as frequently on the red as on the violet edge. These bright lines yield velocities differing considerably from those of hydrogen, being about 40 km. less.

3. A number of weak absorption lines have been measured. Those which are identified are mainly due to helium and silicon. Five helium lines and 4552 A of silicon give a velocity of —13 km. The velocity from K of calcium is about zero but the determination is of small weight.

4. The intensity curves of the hydrogen lines are qualitatively similar to those of P Cygni. Several dark lines (He, Si, Ca) are displaced to the violet with respect to the bright hydrogen lines. The resemblance to P Cygni seems to stop with these characteristics.

5. DM. + 11°4673 may be considered in some respects as intermediate between P Cygni and the well known bright-line stars of Class B.

6. It seems probable that future investigation will disclose facts of interest in regard to the relationships between the following objects:

(a) Novae.
(b) P Cygni, η Carinae.[9]
(c) Stars of the P Cygni Type—Miss Cannon's List.
(d) Bright-line Stars of Class B, e.g., γ Cassiopeiae, ϕ Persei, β Lyrae.

April 7, 1916.

[9] *Harvard Annals, 76,* 36, 1915.

A STUDY OF THE SPECTRUM OF ζ_1 URSAE MAJORIS[1]

By LAURENCE HADLEY

INTRODUCTION AND STATEMENT OF THE PROBLEM

As early as the middle of the seventeenth century ζ Ursae Majoris ($\alpha = 13^h\,20^m$, $\delta = +55°\,23'$) was observed as a double star. This was the first discovery of its kind and was made by Riccioli in 1650. It was again observed as a visual double star in 1700 by Kirch. However, the position angle and distance of this pair were not measured until 1750, when they were recorded by Bradley as 143°.1 and 13″.88, respectively. Many measures have been made and published since that time. The recorded values of the position angle seem to show a very slow relative motion which probably does not exceed 0°.025 per year. The distance between the two components, ζ_1 and ζ_2, as given by the best observers for more than a half century, does not vary greatly on either side of 14.4 seconds of arc. So slow are the changes in these quantities that thousands of years will have passed before a single revolution will be complete.

The data to be found on page 399 of the *Astronomical Observatory of Yale Transactions*, Vol. 2, give 0″.021 ± 0″.008 as the most probable parallax of this star, from which it follows that its distance from the sun is approximately 155 light years and that the linear separation of the two components of this visual pair is not less than 64,000,000,000 miles and it may be much greater than this value, depending on the angle between the line of sight and the line joining the two stars.

Basing her calculation on a parallax of 0″.045, Miss Clerke has estimated that Mizar "sends abroad thirty-eight times more light than our sun".[2] Since there is good reason to believe that the parallax is not greater than half of the value used by Miss Clerke, it follows that the light giving power of this star is probably not less than one hundred and fifty times that of the sun.

Professor Stebbins gives 2.40 as the magnitude of ζ_1 Ursae Majoris. In the *Astrophysical Journal*, Vol. 39, page 475, he makes the following statement as a result of his investigation: "Observations throughout the spectroscopic period give no evidence of eclipses, nor of continuous variation. The light is constant within 0.02 or 0.03 mag."

It is an interesting fact that this second magnitude star should have been the first visual binary discovered and that the brighter of its two components, ζ_1 should have been the first known spectroscopic binary. In making a study of the plates taken with an objective-prism spectrograph at the Harvard College Observatory, Miss Maury observed that the K line of ζ_1 Ursae Majoris appeared as a double line on certain plates, while on many others it was a well defined single line. The separation of the K line was so evident on certain plates that its reality could not be doubted. This discovery was made in 1889 and was the beginning of a new line of most fruitful investigation in Astronomy. The Harvard plates, though numerous, had been taken at irregular intervals and, as a result, the period of this doubling of the lines was not evident. It was erroneously placed at 52 days, thus making the time of a complete revolution 104 days. This period of 104 days is approximately five times the true period, which was first derived by Vogel. The Harvard staff found difficulty in their effort to harmonize the period of 104 days with the doubling of the lines as shown by the plates. At times the lines appeared as sharply defined single lines, when the period of 104 days would have called for a wide separation. However, it was left for Vogel to discover the true time of revolution of this spectroscopic pair and to announce a period which would satisfy the observations.

This star, ζ Ursae Majoris, is of peculiar interest in that the fainter component, ζ_2, has been announced as showing variable radial velocity.

[1] A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

[2] Clerke, *Problems in Astrophysics*, page 290.

Frost and Lee[3], of the Yerkes Observatory, have announced the variation as from —17 km. to +10 km., while Dr. Ludendorff[4] has announced that the range shown by his plates is from —17.3 km. to —7.3 km. Nearly a hundred spectrograms have been measured and reduced by the writer. A frequency curve based on the velocities obtained from these measures conforms closely to the probability curve, thus indicating that the differences are due, largely at least, to accidental errors rather than to real changes, so far as plates made with a single prism instrument are concerned.

It is the purpose of this paper to give the results of a thorough study of ζ_1 Ursae Majoris, the brighter of the two visual components. The results and conclusions will be based on velocities published by Dr. Ludendorff and those which were obtained from the measures of spectrograms[5] made at the Detroit Observatory, Ann Arbor, Michigan. It is the aim in this discussion to treat the observations separately; to make a complete and independent solution for each component of ζ_1 Ursae Majoris; and finally, to coordinate the results of the two sets of observations and of the two components, thus putting the subject upon a basis which will be as complete and definitive as possible.

HISTORICAL

Harvard Observations.[6] As previously stated ζ_1 Ursæ Majoris was the first known spectroscopic binary. The first plate to show the K line distinctly double was made in 1886, but this fact was not observed until 1889. More than 150 plates of this star were made at the Harvard College Observatory between the years 1885 and 1889. These spectrograms were used primarily in connection with the work of the observatory on the classification of stellar spectra. However, some consideration was given to the doubling of the lines; to the meaning of this apparent change in the spectrum; to the probable period; and to the velocity in the line of sight, which would correspond to the relative displacement of the lines as observed. There was considerable uncertainty as to the period, but it was thought to be approximately 104 days. Professor Pickering derived the relative velocity of the two components of this spectroscopic binary. Using the displacements of the K line, he found the relative velocity to be 94 miles per second, and from the magnesium line, λ 4481, he placed the value at 102 miles per second. In this connection he says it was not probable that the plates were made at the time of a maximum displacement, hence the maximum velocity is certainly not less than 100 miles per second.[7]

Potsdam Observations. During the months of March and April, 1901, Dr. Ludendorff and Dr. Eberhard secured a series of plates of ζ_1 Ursæ Majoris with Spectrograph IV of the 33 cm. refractor of the Potsdam Observatory. Vogel undertook the measurement and reduction of these plates. The results of his work are given in Vol. XIII, page 324, of the *Astrophysical Journal.* The results are based on the relative velocities of one component with respect to the other and not on the velocities of each component with respect to the center of mass of the system. The measures of only 25 plates are included in Vogel's publication. When Dr. Ludendorff, at a later time, discussed this series of plates, he rejected 13 of the 25 used by Vogel as being of uncertain value, owing to the very small relative displacement of the lines. In Dr. Ludendorff's paper he states that the time recorded is that of the middle of the plate's exposure. Since the time as given by Vogel for these same plates is from 20 to 30 minutes earlier, it seems to be a reasonable supposition that he gave the time for the beginning of the exposure. This would introduce an appreciable error, particularly in the steepest part of the velocity curve. In consideration of this fact and the fact that the good plates are included in the data published by Dr. Ludendorff, which will be discussed in detail, nothing further will be

[3] *Astronomische Nachrichten*, Vol. 177, page 171.

[4] *Astronomische Nachrichten*, Vol. 177, page 9.

[5] For complete description of the apparatus employed and the constants of the instruments see *Publications of the Detroit Observatory*, Vol. 1.

[6] *Monthly Notices*, Vol. 50, page 296.
Harvard College Observatory Circular, No. 11.
Harvard College Observatory Annals, Vol. 26, page xvii.
Astrophysical Journal, Vol. 8, page 174.

[7] *American Journal of Science*, Third Series, Vol. 39, page 46.

done with these earlier results except to give the elements which Dr. Eberhard derived by the method of Lehmann-Filhés from Vogel's measures. The elements follow:

$$
\begin{aligned}
T_0 &= 1901, \text{ March } 28.60. \quad (\text{Relative motion in line of sight} = 0),\\
T &= 1901, \text{ March } 28.88,\\
\omega &= 101^\circ.3,\\
e &= 0.502,\\
\log \mu &= 9.4843,\\
\mu &= 17^\circ.476,\\
P &= 20.6 \text{ days},\\
a \sin i &= 35 \text{ million km.},\\
m_1 + m_2 &= \frac{4 \cdot \odot}{\sin^3 i}.
\end{aligned}
$$

Dr. Ludendorff and Dr. Eberhard continued their observations in 1901 throughout the months of May and June. The work was taken up again in the years 1903, 1905, and 1906. In all, 118 spectrograms were secured. Of these 118 plates, the measures by Dr. Ludendorff of 59 are given in the *Astronomische Nachrichten*, Vol. 180, No. 4313, page 278. These measures have not been used for the determination of a complete set of elements. They were used for finding the center of mass velocity: the ratio of the masses; and for improving the period as announced by Vogel.

Since a full discussion of Dr. Ludendorff's measures will be taken up in this paper, the details of his work will be omitted and his final results stated. The period, he says, is correct to within a few thousandths of a day. The probable errors of the other quantities show what confidence may be placed in their determination.

$$
\begin{aligned}
P &= 20.536 \text{ days},\\
\gamma &= -12.6 \pm 0.49 \text{ km.},\\
\frac{m_1}{m_2} &= 1.014 \pm 0.018,
\end{aligned}
$$

where P is the period; γ the velocity of the center of mass of the system; and $\frac{m_1}{m_2}$ the ratio of the masses of the two components.

It is worthy of note at this point that the values of γ and $\frac{m_1}{m_2}$ are somewhat uncertain. The values given above were derived from the entire series of 59 plates. Dr. Ludendorff also divided the plates into two groups; the first, containing the plates made in 1901, the second, those of 1903, 1905, and 1906. The first group contained 26 plates and the second 33. When these two groups were considered separately, unexpected differences were found as shown below:

1901.	1903-6.
$\gamma = -13.2$ km.,	$\gamma = -12.2$ km.,
$\frac{m_1}{m_2} = 0.980.$	$\frac{m_1}{m_2} = 1.035.$

These differences will be discussed later, but it may be well to note at this point that such change in the ratio of the masses would not be possible, and that the change in center of mass velocity seems to be improbable, unless there is a third body in the system, a resisting medium, or other disturbing factors.

DERIVATION OF ELEMENTS.

Potsdam Measures. The velocities referred to above, as derived by Dr. Ludendorff, will now be discussed in full. Table I contains the data as given in the *Astronomische Nachrichten*. Column (1) gives the number of the plate; column (2) gives the Greenwich mean time for the middle of the observation; column (3) gives the phase as counted from 1912 March 10.000, using the final value of the period; the next three columns contain data for Component 1, the first gives the number of lines measured, the second gives the velocity in the line of sight, and the third gives the error in the sense, observed minus computed; the next three columns refer to Component 2, giving the same data as was given for Component 1; the last column gives the weight to be assigned. It is difficult for anyone, other than he who measures the plates, to determine the weights which should be assigned. Hence, the writer adopted Dr. Ludendorff's assignment of weights and used the same plan in the reduction of his own measures. It is as follows. Unless there be good reason for an increase or decrease in the weight to be assigned to a plate, it is made equal to one-half of the sum of the number of lines measured on the two components. There are other methods of assigning weights which are better, but it seemed desirable to treat both sets of data exactly alike. Hence, the plan adopted by the observer at Potsdam was used in both cases.

TABLE I. VELOCITIES

POTSDAM OBSERVATIONS.

NO.	DATE, G. M. T.		PHASE.	COMPONENT 1.			COMPONENT 2.			WT.
				N.	V.	O–C.	N.	V.	O–C.	
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	1901		DAYS		KM.	KM.		KM.	KM.	
1	Mar.	24.383	0.989	3	+ 42	+ 1.8	5	− 67	− 8.3	4
2		26.393	2.999	4	+ 42	− 3.7	3	− 66	+ 7.6	3
3		29.293	5.899	0	..	....	1	+ 36	+ 1.5	0
4		30.333	6.939	4	− 90	− 4.2	3	+ 64	+ 3.8	3
5	Apr.	2.313	9.919	0	..	....	4	+ 44	+ 2.5	0
6		16.333	3.402	11	+ 44	− 2.2	3	− 78	− 2.7	5
7		17.333	4.402	4	+ 36	+ 2.3	2	− 59	+ 5.8	3
8		20.323	7.392	5	− 88	− 9.7	3	+ 47	− 8.5	2
9		21.333	8.402	3	− 76	− 2.7	2	+ 38	− 11.5	2
10		22.333	9.402	3	− 63	− 2.2	3	+ 46	+ 8.7	3
11		23.323	10.392	4	− 52	− 3.2	2	+ 22	− 5.4	3
12		24.343	11.412	3	− 40	− 0.2	1	+ 16	− 2.8	2
13	May	2.363	19.432	2	+ 23	+ 2.7	1	− 48	− 5.8	1
14		3.353	20.422	2	+ 22	− 5.2	2	− 53	− 3.2	2
15		5.363	1.869	7	+ 46	+ 8.7	6	− 68	− 6.7	6
16		12.363	8.896	4	− 67	− 0.5	3	+ 16	+ 4.5	3
17		13.343	9.876	1	− 62	− 6.8	3	+ 34	+ 2.2	2
18		14.343	10.876	2	− 54	− 8.8	4	+ 20	− 2.6	3
19		24.373	0.369	5	+ 35	+ 4.2	3	− 60	− 6.2	4
20		31.353	7.349	7	− 85	− 0.2	5	+ 56	− 2.8	6
21	June	1.353	8.349	7	− 72	+ 1.8	5	+ 48	− 0.8	6
22		13.373	20.369	2	+ 38	+ 11.2	1	− 47	+ 2.8	1
23		19.413	5.873	3	− 65	− 10.5	4	+ 41	+ 6.8	3
24		20.353	6.813	6	− 87	− 1.5	2	+ 56	− 4.2	4
25		21.393	7.853	5	− 82	− 1.7	8	+ 50	− 4.8	3
26		23.363	9.823	3	− 60	− 4.2	4	+ 32	− 0.8	3
	1903									
27	Apr.	28.432	6.190	8	− 69	+ 1.5	8	+ 51	+ 2.4	8
28		30.432	8.190	2	− 75	+ 1.5	2	+ 58	+ 7.4	2
29	May	13.313	0.534	5	+ 40	+ 8.2	5	− 48	+ 7.3	5
30		14.373	1.594	4	+ 46	+ 6.8	6	− 56	+ 7.7	5
31		20.323	7.544	5	− 75	+ 8.2	9	+ 50	− 7.2	7
32		22.323	9.544	4	− 60	− 1.4	3	+ 39	+ 3.5	3
33		23.323	10.544	3	− 57	− 8.4	2	+ 28	+ 2.2	2
	1905									
34	Apr.	20.353	10.335	4	− 53	− 2.7	4	+ 25	− 2.8	4
35		30.333	20.315	2	+ 21	− 5.8	2	− 47	+ 2.3	2
36	May	3.353	2.799	7	+ 40	− 5.0	7	− 67	+ 5.8	7
37		4.363	3.809	8	+ 36	− 8.2	7	− 78	− 3.2	7

TABLE I. VELOCITIES.

POTSDAM OBSERVATIONS—CONT'D.

NO.	DATE, G. M. T.		PHASE.	COMPONENT 1.			COMPONENT 2.			WT.
				N.	V.	O–C.	N.	V.	O–C.	
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	1905		DAYS		KM.	KM.		KM.	KM.	
38	May	9.343	8.789	1	−70	− 1.6	1	+39	− 5.8	1*
39		25.343	4.252	5	+43	+ 5.5	5	−75	− 5.5	5
40		27.343	6.252	3	−70	+ 2.5	3	+44	− 5.6	3
41		28.343	7.252	4	−83	+ 2.8	5	+65	+ 6.7	4
42		29.343	8.252	6	−77	− 1.2	7	+55	+ 4.6	6
43		30.363	9.272	4	−60	+ 3.3	3	+39	+ 0.2	3
44		31.363	10.272	9	−49	+ 2.3	9	+26	− 2.6	9
45	June	19.423	8.796	3	−64	+ 4.6	5	+43	− 0.7	4
	1906									
46	Mar.	29.403	4.266	4	+41	+ 3.2	1	−36	+33.3	0†
47	Apr.	1.373	7.236	2	−83	+ 2.7	2	−62	+ 2.8	2
48		3.373	9.236	1	−73	− 9.8	1	+28	−10.6	1*
49		15.353	0.679	2	+33	+ 0.2	3	−63	− 6.7	2
50		17.303	2.629	3	+50	− 4.8	1	−75	− 3.6	2
51		21.363	6.689	3	−89	− 3.6	5	+58	− 2.0	4
52		23.313	8.639	3	−68	+ 2.5	6	+51	+ 5.0	4
53		24.343	9.669	4	−55	+ 2.5	5	+31	− 3.3	4
54	May	5.333	0.123	7	+20	− 0.3	11	−51	+ 0.8	9
55		6.323	1.113	8	+37	+ 1.2	6	−65	− 5.4	7
56		7.343	2.133	6	+41	− 1.2	5	−66	+ 2.2	5
57		8.323	3.113	3	+53	+ 6.8	3	−64	+10.2	3
58		13.333	8.123	6	−82	− 6.0	7	+59	+ 8.5	6
59		14.323	9.113	4	−59	+ 5.5	3	+44	+ 3.7	3

* Under exposure.

† Only 1 line on Comp. 2.

Normal places. The final velocities as given in Table I were combined into sixteen normal places with the phase as the basis of grouping. Care was taken that the limits of phase for each normal place be so small that the velocity curve over that interval would be essentially straight. The weight assigned to each place was determined by the number of good, measurable lines on all of the plates used in making up the normal place. The phases as given in column (2) have been reduced to the sun. Column (3) gives the limits within which the phases of the plates fall which were used in forming each normal place. The velocities of the two components are given; also the residuals in the sense, observed minus computed, based on the final elements.

The normal velocities given in Table II are plotted in Plate VI. The exact positions are shown by the centers of the small circles.

From the phases which had been reduced to the sun and the velocities corrected for curvature as given in Table II, velocity curves were plotted. From these curves preliminary elements for each component were derived by use of the Forty-five Degree Chordal Method.[8] The two components were carried entirely through, separately. Component 1 having been taken up first. But before

[8] *Astrophysical Journal*, Vol. 28, page 212.

taking up either component it is desirable to settle the question of the period.

Period. In order to obtain an accurate value for the period, Ludendorff's velocities were plotted with P taken equal to 20.536 days which was known already to be a good value. The Ann Arbor velocities were similarly plotted and the curves transferred to tracing cloth which was then fitted, as nearly as could be, to the curves from Ludendorff's measures. With the curves in the best agreement, the time-axes were compared at six different, well defined points and the average of the six determinations gave $\Delta T = +0.07$ days.

The mean time for the Potsdam observations was taken as 1903.5 and for the Ann Arbor observations, 1912.6. The time interval between these two dates is 9.1 years which is approximately 161 periods. From this it follows that

$$\Delta P = \frac{+0.07}{161} = +0.00044 \text{ days.}$$

This correction is much smaller than might have been expected since Ludendorff stated that his determination, $P = 20.536$, was correct within a few thousandths of a day. By applying the correction which was found, we have $P = 20.53644$ days as the true period. From the method of its determination and the large time interval over which it extended, we shall adopt this as final and no further correction for this element will be sought in connection with the least square solution. The period having been accurately found, the value of μ, the mean daily motion, was easily derived.

$$\mu = 17^\circ.5298.$$

Since μ and P are mutually dependent, the values of these two quantities will be accepted without further correction. Since $\delta\mu$ will not be needed in the least-square formulæ, only five unknowns will occur and the computation will be greatly simplified.

TABLE II. NORMAL PLACES.

POTSDAM OBSERVATIONS.

NO. (1)	PHASE. (2)	LIMITS OF PHASE. (3)	WT. (4)	COMPONENT 1. VELOCITY. (5)	COMPONENT 1. O—C. (6)	COMPONENT 2. VELOCITY. (7)	COMPONENT 2. O—C. (8)
1	6.135	5.87 to 6.26	0.56	—69.11	+0.29	+48.10	+1.36
2	6.802	6.68 to 6.94	0.44	—88.93	—3.46	+59.08	—0.95
3	7.430	7.23 to 7.56	1.00	—82.06	+2.14	+55.32	—2.80
4	8.250	8.12 to 8.41	0.88	—76.73	—1.35	+52.96	+2.96
5	8.768	8.63 to 8.90	0.48	—66.60	+2.30	+46.04	+1.87
6	9.260	9.11 to 9.41	0.40	—61.90	+0.96	+41.50	+2.76
7	9.711	9.54 to 9.92	0.48	—58.67	—1.11	+33.75	—0.18
8	10.336	10.27 to 10.55	0.72	—51.28	—0.64	+25.33	—2.29
9	11.144	10.87 to 11.42	0.16	—47.00	—4.56	+18.00	—2.02
10	20.212	19.43 to 20.43	0.24	+24.50	—1.37	—49.27	—0.98
11	20.828	20.65 to 21.07	0.72	+28.89	—1.27	—52.17	+0.98
12	21.543	21.21 to 21.65	0.52	+37.92	+2.82	—65.31	—6.37
13	22.412	22.13 to 22.67	0.64	+44.44	+3.70	—63.62	+2.40
14	23.415	23.16 to 23.65	0.60	+44.39	—1.08	—67.73	+5.47
15	24.175	23.93 to 24.35	0.48	+30.65	—5.29	—78.35	—3.31
16	24.844	24.79 to 24.94	0.32	+40.49	+4.43	—69.10	—1.55

Component 1. Velocity curves having been drawn with as much accuracy as was possible, the following set of preliminary elements was derived:

PRELIMINARY ELEMENTS (COMPONENT 1).

$$P = 20.53644 \text{ days},$$
$$\mu = 17^\circ.5298,$$
$$T = 5.600 \text{ days from 1912 March 10.000.}$$
$$e = 0.5440,$$
$$\omega = 101^\circ\ 12'.2,$$
$$K = 68.0 \text{ km.},$$
$$V_0' = -18.0 \text{ km.},$$
$$\gamma = -10.82 \text{ km.}$$

From these elements an ephemeris was computed and the residuals found in the sense, observed minus computed. The agreement being sufficiently close between observation and computation, a least square solution was undertaken. The sixteen normal places gave sixteen equations of condition. The usual method of treatment gave the five normal equations which follow. The notation is that of Schlesinger in his paper published in the *Allegheny Observatory Publications,* Vol. 1, No. 6.

NORMAL EQUATIONS.

$$\begin{aligned} 8.641\Gamma - 0.870\kappa - 3.248\pi - 0.712\epsilon - 0.271\tau + 8.794 &= 0, \\ +5.730\kappa + 0.383\pi + 1.209\epsilon + 0.014\tau + 7.264 &= 0, \\ +2.910\pi + 0.730\epsilon + 0.715\tau + 0.620 &= 0, \\ +0.945\epsilon + 0.258\tau + 0.478 &= 0, \\ +0.305\tau + 0.866 &= 0. \end{aligned}$$

The five normal equations were treated after the method given in Vol. 1 of Chauvenet's *Practical Astronomy.* A solution of these equations gave the following values:

$$\tau = +0.4844,$$
$$\epsilon = +2.6638,$$
$$\pi = -3.1655,$$
$$\kappa = -1.9489,$$
$$\Gamma = -2.1693.$$

To check the accuracy of the numerical work, the values of the unknowns were substituted in the normal equations. The agreement was found to be satisfactory, the largest of the residuals being 0.005 while the average value was 0.003. From these values of the unknowns the corrections to be applied to the elements were obtained. The corrections and the corrected elements follow:

CORRECTIONS.

$$\delta K = -1.949 \text{ km.},$$
$$\delta\omega = +2^\circ\ 40'.0,$$
$$\delta e = -0.01248,$$
$$\delta T = +0.00577 \text{ days},$$
$$\delta\gamma = -0.851 \text{ km.}$$

CORRECTED ELEMENTS.

$$T = 5.60577 \text{ days},$$
$$e = 0.53152,$$
$$\omega = 103^\circ\ 52'.2,$$
$$K = 66.051 \text{ km.},$$
$$\gamma = -11.671 \text{ km.}$$

The residuals recorded in column 6 of Table II were found by comparison of the observed velocities with an ephemeris computed from the corrected elements. The differences between these residuals and those found from the normal equations were so small that the second order terms neglected in making a least square solution were evidently inappreciable, hence a repetition of the least square solution was not necessary.

It is now possible to find the quantity, $a \sin i$, by use of the formula,

$$a \sin i = [4.13833]\ (1 - e^2)^{1/2} K \cdot P.$$

Substituting in the equation we obtain the following value:

$$a \sin i = 15{,}800{,}000 \text{ km.}$$

The probable errors given in connection with certain of the elements were computed by the usual method. The value for the mass, m_1, cannot be determined at this point in the solution, but is given here even though derived later. The

final elements for Component 1 derived from Ludendorff's measures follow:

FINAL ELEMENTS. (COMPONENT 1).

$$P = 20.53644 \text{ days},$$
$$\mu = 17^\circ.5298,$$
$$T = 5.6058 \pm 0.0700 \text{ days from 1912, March 10.000},$$
$$e = 0.53152 \pm 0.01024,$$
$$\omega = 103^\circ\ 52'.2 \pm 2^\circ\ 47'.9,$$
$$K = 66.05 \pm 0.77 \text{ km.},$$
$$\gamma = -11.67 \text{ km.},$$
$$a \sin i = 15{,}800{,}000 \text{ km.},$$
$$m_1 = \frac{1.57 \odot}{\sin^3 i}.$$

The probable errors in ω and T indicate some uncertainty in the values of these quantities. This was to be expected since, in forming the elimination equations, the quantity $[ee.\ 4]$ is very small. This quantity, $[ee.\ 4]$, is a function of the coefficients found in the normal equations and since it nearly vanishes owing to the peculiarities of the normal places and the velocity curve, the value of τ and hence of δT are uncertain. The value of ω changes with the value of T, therefore, it is uncertain also.

The least square solution having been completed, the following results may be stated:

1. The sum of the weighted squares of the residuals for the sixteen normal places was reduced from 87.48 to 53.52.

2. The probable error of a normal place of weight unity was found to be $\pm$ 1.49 km.

3. The residuals recorded in column 6 of Table I were scaled from the final velocity curve, Plate VI. These residuals gave $\pm$ 3.5 km. as the probable error of the average plate and $\pm$ 2.3 km. as the probable error of the best plates of the series.

Next in order should come a like treatment of the measures of Component 2. While the discussion is more brief, the details of the process were identically the same as those used in Component 1.

Component 2. As in the preceding case, preliminary elements were derived and residuals found by a comparison of the observed and the computed velocities for each of the sixteen normal places.

PRELIMINARY ELEMENTS. (COMPONENT 2).

$$P = 20.53644 \text{ days},$$
$$\mu = 17^\circ.5298,$$
$$T = 5.56 \text{ days from 1912, March 10.000},$$
$$e = 0.5410,$$
$$\omega = 282^\circ\ 6'.4,$$
$$K = 67.0 \text{ km.},$$
$$V_0' = -5.0 \text{ km.},$$
$$\gamma = -12.61 \text{ km.}$$

The normal equations derived from the sixteen equations of condition took the following form:

NORMAL EQUATIONS.

$$8.64\Gamma + 0.813\kappa + 2.459\pi + 0.836\epsilon + 0.297\tau + 4.712 = 0.$$
$$5.737\kappa + 0.489\pi + 1.197\epsilon + 0.069\tau - 0.912 = 0.$$
$$2.003\pi + 0.765\epsilon + 0.704\tau - 2.062 = 0.$$
$$0.794\epsilon + 0.247\tau + 1.459 = 0.$$
$$0.287\tau - 0.458 = 0.$$

As indicated in connection with Component 1, the elimination equations were formed from these normal equations. Again the value of $[ee.\ 4]$ was small enough to indicate some uncertainty in the values of T and ω.

The five normal equations gave the following as the values of the unknowns:

$$\tau = +0.8046,$$
$$\epsilon = -5.2975,$$
$$\pi = +2.4510,$$
$$\kappa = +1.1694,$$
$$\Gamma = -0.8679.$$

The accuracy of the numerical work was shown by the small residuals which were obtained when the values of the unknowns were substituted in the normal equations, the average value for the five equations being 0.005, while the largest was only 0.007. The corrections and the corrected elements follow:

CORRECTIONS.

$$\delta K = +1.169 \text{ km.},$$
$$\delta\omega = -2^\circ\ 5'.8,$$
$$\delta e = +0.02530,$$
$$\delta T = +0.00983,$$
$$\delta\gamma = -0.0596 \text{ km.}$$

FIRST CORRECTED ELEMENTS.

$$K = 68.169 \text{ km.},$$
$$\omega = 280^\circ\ 0'.6,$$
$$e = 0.56630,$$
$$T = 5.56983 \text{ days from 1912, March 10.000},$$
$$\gamma = -12.670 \text{ km}$$

The residuals (observed minus computed velocities) were found from the normal equations and also from an ephemeris, the corrected elements being used. The differences for eight of the sixteen normal places exceeded 0.1 and ranged in value from 0.11 to 0.31. To make sure that the second order terms were not affecting the results, a second least square solution was made in which the corrected elements were taken as a beginning. The normal equations follow:

NORMAL EQUATIONS (SECOND SOLUTION).

$$8.64\Gamma + 0.879\kappa + 3.596\pi + 0.658\epsilon + 0.318\tau + 1.958 = 0,$$
$$5.567\kappa + 0.228\pi + 1.272\epsilon + 0.002\tau - 0.876 = 0,$$
$$3.073\pi + 0.716\epsilon + 0.651\tau - 0.686 = 0,$$
$$0.936\epsilon + 0.238\tau - 1.217 = 0,$$
$$0.246\tau + 0.066 = 0.$$

This set of equations gave the following as the values of the unknown:

$$\tau = -10.8148,$$
$$\epsilon = +\ 2.8932,$$
$$\pi = +\ 3.6645,$$
$$\kappa = -\ 0.4082,$$
$$\Gamma = -\ 1.5328.$$

As in the other solution, the value of the quantity, [*ee*. 4], was small. To check the numerical computation, the values just derived were substituted in the normal equations. The average residual obtained from the five equations was 0.005, which showed complete agreement between the values of the unknowns and the equations.

The corrections and the corrected elements resulting from the second least square solution are given below.

CORRECTIONS.

$$\delta K = -0.4082 \text{ km.},$$
$$\delta\omega = -3^\circ\ 4'.8,$$
$$\delta e = -0.01304.$$
$$\delta T = -0.11832 \text{ days},$$
$$\delta\gamma = +0.706 \text{ km.}$$

CORRECTED ELEMENTS.

$$K = 67.761 \text{ km.},$$
$$\omega = 276^\circ\ 55'.8,$$
$$e = 0.55326,$$
$$T = 5.45151 \text{ days},$$
$$\gamma = -11.964 \text{ km.}$$

The agreement between residuals by the normal equations and by ephemeris was satisfactory, thus indicating that second order terms were negligible. Hence, a third solution would yield unimportant changes.

As in the case of Component 1, the quantity $a \sin i$ was found. Its value follows:

$$a \sin i = 15{,}940{,}000 \text{ km.}$$

It is now possible to find the masses of the two components in terms of the mass of the sun and the angle i. The two values follow:

$$m_1 = \frac{1.57\odot}{\sin^3 i},$$

$$m_2 = \frac{1.46\odot}{\sin^3 i}.$$

The value of $\sin^3 i$ cannot be greater than unity and hence the numerators of these expressions represent the minimum values. However, in finding the ratio of the masses this indeterminate quantity cancels out and the following value is obtained:

$$\frac{m_1}{m_2} = 1.079.$$

As the final elements for Component 2, derived from the Ludendorff measures, we have the following:

FINAL ELEMENTS (COMPONENT 2).

$$P = 20.53644 \text{ days},$$
$$\mu = 17^\circ\ 5298,$$
$$T = 5.4515 \pm 0.0835 \text{ days from 1912, March 10.000},$$
$$e = 0.55326 \pm 0.01241,$$
$$\omega = 276^\circ\ 55'.8 \pm 2^\circ\ 17'.5,$$
$$K = 67.76 \pm 0.98 \text{ km.},$$
$$\gamma = -11.96 \text{ km.},$$
$$a \sin i = 15{,}940{,}000 \text{ km.},$$
$$m_2 = \frac{1.46\odot}{\sin^3 i},$$
$$\frac{m_1}{m_2} = 1.079.$$

The uncertainty in the determination of T and ω is again evident from the probable errors.

Having arrived at a set of elements which give satisfactory agreement between observed and

computed velocities, the following points of interest should be noted:

1. The sum of the weighted squares of the residuals was reduced from 99.66 to 83.12 by the first least square solution and to 75.83 by the second.

2. The probable error of a normal place of weight unity was found to be ± 1.77 km.

3. The residuals recorded in column 9 of Table I were scaled from the final velocity curve, Plate VI. From these residuals, the probable error of an average plate was found to be ± 3.7 km. and for the best plates of the series it was found to be ± 2.4 km.

Velocity Curves. The velocity curves shown in Plate VI were plotted from an ephemeris computed from the final elements for each of the two components as derived from the Potsdam measures. Points were located at frequent intervals throughout the entire length of the curves so that they might give an accurate representation of the velocities in all parts of the orbits. Beginning at the left border of the plate, the upper curve belongs to Component 1 and the lower one to Component 2.

This completes the discussion of Dr. Ludendorff's measures with the exception of certain questions arising in connection with the ratio of the masses and the center of mass velocity. These two points will be taken up and discussed later in this paper.

ANN ARBOR OBSERVATIONS

Observations of ζ_1 Ursæ Majoris were begun at the Detroit Observatory March 10, 1912, and were continued until August 27, of the same year. During the following year, a few plates were made in order to strengthen the weak parts of the velocity curve. In all 137 spectrograms were made. Of this number, 128 were measurable, 90 plates showing the lines measurably separated and 38 showing single lines. In general, lantern slide plates were used. Of the 128 measurable plates, 122 were of this variety, while 6 were Seed 23. The average time of exposure for the lantern slide plates was 9.1 minutes for 108 plates. Fourteen lantern slide plates were made with a very narrow slit with an average time of exposure equal to 35 minutes. The 6 Seed 23 plates required an exposure of 5.4 minutes on the average. While much time might have been saved by using the more rapid plates, the coarser grain made measuring much more difficult and in some cases, impossible. The lantern slide plates should be used on this and similar binaries in preference to more rapid plates. It is an interesting fact that the spectrograms made with the one prism instrument of the Detroit Observatory gave points on the velocity curve almost as near the cross-points of the curves as did the plates made with the three prism instrument at Potsdam.

Standard of Dispersion. The writer has previously measured and reduced a hundred plates of γ Lyræ. For use in that piece of work, a standard was obtained by taking the average screw reading for each of twenty-eight well defined titanium lines of the comparison spectrum as measured on ten of the best plates of the series. Three good lines, well distributed over the region of the spectrum to be used, were selected for the determination of the constants of the corrected Hartmann interpolation formula. This set of constants, and hence the same standard of dispersion, were used in the reduction of the plates of ζ_1 Ursæ Majoris.

Measures. The spectrum of ζ_1 Ursæ Majoris is usually classified as belonging to Class Ap, meaning that the star is of division A of the Harvard classification with certain peculiarities. The measures have been considered as difficult by each astronomer who has worked on the plates of this star. Vogel says, "When the spectra are more strongly displaced with reference to one another, most of the lines which appear double, become so weak that the measurement of their separation is rendered very difficult. On some plates, in fact, it was found possible to measure only the Mg line, λ 4481. It is to be noted that the fine lines of the spectra of Class Ia2 are only obtained when the exposure time is exactly correct, and the plate correctly developed. In general, the measures are to be classed as difficult, either on account of their excessive fineness or, in case of the Mg and H lines, on account of the too great width and diffuseness of the lines." All other measurers have experienced the difficulties set forth in the quotation from Vogel. The uncertainty of the measures is shown by the

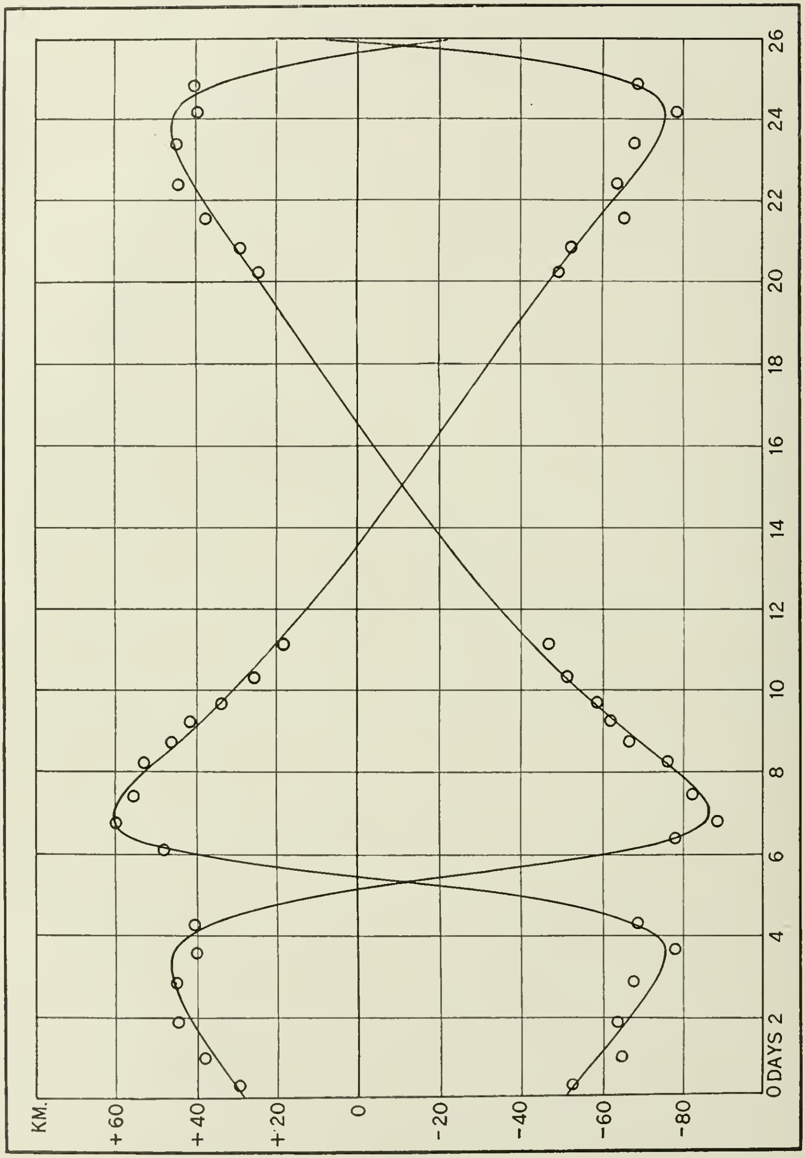

PLATE VI. VELOCITY CURVES OF ζ_1 URSAE MAJORIS. VELOCITIES BY LUDENDORFF

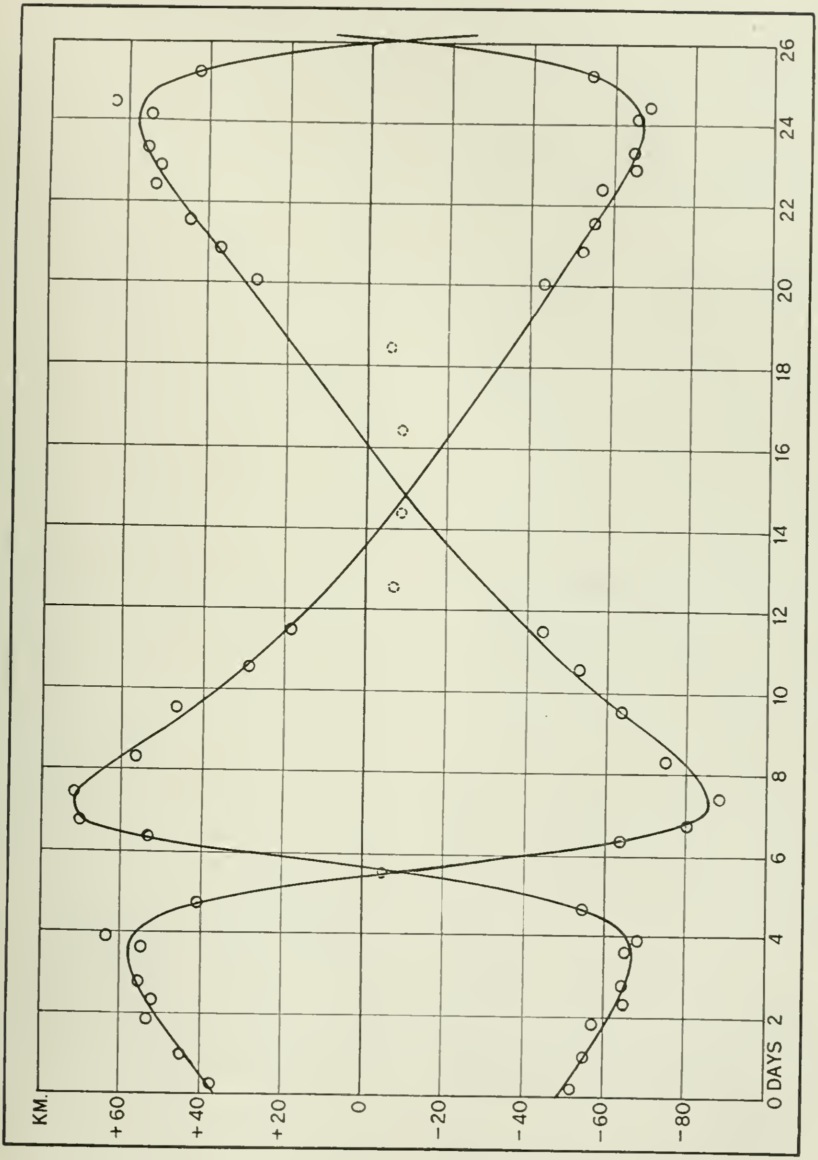

PLATE VII. VELOCITY CURVES OF ξ_1 URSAE MAJORIS. ANN ARBOR VELOCITIES

size of the probable error of a single plate and was also very evident from the lack of agreement in the measures of the displacement of the various lines on a single plate.

Identification of lines. Of the 30 lines used in this series of plates, all except 5 were identified with certainty so that the corresponding wave-lengths were obtainable from the tables giving such data. The wave-lengths for the five unidentified lines were found as will be explained later.

Preliminary velocities. Having identified as many lines as possible, the next process was the determination of the velocities resulting from the displacements shown by the known lines. The wave-lengths adopted were taken from recognized authorities as will be seen by referring to Table III. Using the corrected Hartmann interpolation formula and the constants previously found, the screw reading for zero displacement of each star line was computed and also the corresponding factor necessary to transform displacements in terms of screw readings into velocities in km. per second. The velocity, as given from the displacement of each known measured line on every plate, was then found. The arithmetical mean of the velocities as shown by the lines of each plate was taken as the velocity for that plate unless the lines were clearly of unequal weight. By this means, a complete set of preliminary velocities was determined.

Unknown lines. These preliminary velocities and the proportionality factors of the unknown lines for the purpose of changing screw readings into velocities having been determined, it was not difficult to reverse the process and find the wave-lengths of the lines so that they would give the same velocity as that shown by the known lines of the plate. This was done for each unknown line for all of the plates on which it was measured and a weighted mean of the results taken as the wave-length of that particular unidentified line. The results are shown in Table III. The accuracy of these wave-lengths and confidence to be placed in their determination is shown by their probable errors and by the number of measures.

Use of the newly determined lines. The probable errors in the values of the wave-lengths, which were found, indicate such accuracy as would lead to a better determination of the velocities from the measures of the separate plates if these new lines were included. Hence, the velocities were computed, use being made of the displacements of these new lines. That the values were improved was very evident from the closer agreement between the velocities as determined from successive plates made on the same night.

Final velocities. One other correction was necessary before the velocities could be accepted as final. The residuals for each line on all of the plates, which showed measurable separation, were found. These residuals came from a comparison of the velocity as given by the line itself with the velocity as given by the plate. A correction to be applied to each line was then found which would reduce to zero the algebraic sum of the residuals of that line for all of the plates on which it was measured. These corrections produced noticeably better agreement between observed velocities and those computed from the final elements.

Table III. This table contains data concerning the lines used in this investigation. The first column gives the assumed wave-length of the line. The second column gives the authority. R stands for Rowland, K for Kayser, L for Lockyer, RHC for Professor Ralph H. Curtiss of this observatory in his paper on β Lyræ, L H for the value as determined by the writer of this paper. The third column gives the intensity on a scale of 1 to 20. The fourth column gives the element, if it is known. The fifth column gives the wave-length in ζ_1 Ursæ Majoris, from which the final velocities were obtained. Columns 6, 7, and 8 give the number of times the lines were measured on plates showing separation of the components.

Following the table is to be found the computed wave-length for each of the unknown lines, the probable error, and the number of measures on which the determination depended. The probable errors do not, however, take into account the very slight inaccuracies affecting the determination of the wave-lengths by the corrected Hartmann interpolation formula.

Ann Arbor velocities. The results of the measures of the plates made at this Observatory are given in Tables IV and V. Table IV contains

TABLE III. WAVE-LENGTHS.

ASSUMED WAVE-LENGTH. (1)	AUTHORITY. (2)	INTENSITY. (3)	ELEMENT. (4)	WAVE-LENGTH IN ζ1 URSAE MAJORIS. (5)	NUMBER OF MEASURES. COMP. 1 (6)	COMP. 2 (7)	TOTAL. (8)
3905.670	R	2	Si	3905.724	9	10	19
3913.640	K	2	Ti	3913.605	15	13	28
3933.825	R	10	Ca	3933.839	27	27	54
4005.730	RHC	2	?	4005.627	21	22	43
4045.975	R	3	Fe	4045.989	60	58	118
4063.770*	LH¹	1	?	4063.773	42	43	85
4067.30	L	1	Enh. Ni.	4067.397	21	19	40
4071.908	R	1	Fe	4071.983	18	18	36
4077.89	L	2	Enh. Sr.	4077.928	41	40	81
4101.927	R	20	Hδ	4101.946	1	1	2
4128.204	RHC	1	Si	4128.336	16	13	29
4132.139	K	1	Van.	4132.455	10	12	22
4136.869*	LH²	1	?	4136.826	9	8	17
4144.038	R	1	Fe	4143.992	31	28	59
4163.882*	LH³	1	?	4163.877	6	6	12
4173.765	RHC	1	?	4173.748	36	38	74
4179.070	RHC	1	?	4179.146	7	5	12
4215.680	K	1	Sr	4215.725	43	42	85
4233.543*	LH⁴	1	?	4233.505	39	39	78
4290.382	K	1	Ti	4290.327	22	26	48
4308.072*	LH⁵	1	?	4308.114	17	15	32
4325.939	K	2	Fe	4325.799	10	10	20
4340.634	R	20	Hγ	4340.662	3	3	6
4352.42†	K	2	Sb	....	..	..	..
4443.99	L	1	Enh. Ti	4444.031	11	11	22
4481.397	RHC	6	Mg	4481.462	46	45	91
4534.171	L	2	Enh. Ti	4534.220	3	0	3
4549.808†	R	2	Ti & Co	....	..	..	..
4572.473†	K	1	Ce	....	..	..	..
4861.527†	R	20	Hβ	....	..	..	..

* LH¹ λ 4063.770 ± 0.012, 71 measures.
* LH² λ 4136.869 ± 0.040, 10 measures.
* LH³ λ 4163.882 ± 0.035, 10 measures.
* LH⁴ λ 4233.543 ± 0.019, 54 measures.
* LH⁵ λ 4308.072 ± 0.039, 24 measures.
† This line was measured only on plates showing lines unresolved.

data coming from the plates which showed the lines of the two spectra measurably separated and Table V, the data coming from the plates in which the lines were not resolved and hence had to be measured as single lines. The different columns of these tables give the same data as the corresponding columns in the table of Ludendorff's measures. The initials in column (2) are those of the observer at the telescope; Prof. Curtiss, Mr. Mellor, and the writer. All of the measures were made by the writer. The measuring engine was carefully tested for screw error, which was found to be inappreciable. Hence, no correction was needed for that source of error.

TABLE IV. VELOCITIES.

ANN ARBOR OBSERVATIONS.

PLA. NO. (1)	OBS. (2)	DATE G. M. T. (3)	PHASE. (4)	COMPONENT 1 N (5)	COMPONENT 1 V (6)	COMPONENT 1 O–C (7)	COMPONENT 2 N (8)	COMPONENT 2 V (9)	COMPONENT 2 O–C (10)	WT. (11)
		1912								
310	H	March 10.760	0.760	5	+53.2	+10.2	5	−52.0	+1.5	5
321	H	10.786	0.786	3	+49.8	+6.6	3	−59.9	−6.0	3
333	M	12.792	2.792	8	+64.3	+8.0	7	−49.7	+15.3	7
334	M	12.808	2.808	11	+48.5	−7.8	8	−76.4	−11.4	9
358	M	16.847	6.847	9	−73.8	+7.5	9	+76.6	+6.1	9
359	H	16.912	6.912	11	−75.9	+6.1	11	+79.8	+9.3	11
412	H	29.809	19.809	5	+31.5	+1.9	4	−31.1	+12.4	4
413	M	29.819	19.819	1	+21.0	−8.6	1	−44.5	−1.0	1
421	M	Apr. 5.800	6.264	6	−51.0	+7.0	5	+54.9	+7.9	5
422	H	5.811	6.275	5	−61.2	−3.2	3	+29.7	−17.3	4
435	M	7.754	8.218	9	−65.9	+14.1	10	+52.5	+1.0	9
436	M	7.764	8.228	3	−84.5	−4.5	3	+54.7	+3.2	3
460	M	23.750	3.677	8	+61.2	+3.8	8	−55.1	+11.0	8
461	H	23.756	3.683	7	+54.6	−2.8	7	−69.5	−3.4	7
472	C	26.708	6.635	8	−70.2	+4.8	8	+72.6	+6.4	8
473	M	26.712	6.639	7	−78.8	−3.8	7	+60.6	−5.6	7
475	M	26.738	6.665	9	−88.1	−13.1	9	+58.6	−7.6	9
531	M	May 10.631	0.022	7	+38.2	+2.7	7	−43.1	+5.5	7
533	M	10.671	0.062	4	+44.5	+7.5	3	−47.6	+1.6	3
535	M	14.589	3.980	7	+53.4	−2.4	7	−73.2	−8.2	7
536	M	14.594	3.985+	8	+66.1	+10.3	8	−73.6	−8.6	8
555	M	17.578	6.969	5	−91.4	−8.4	4	+59.7	−11.5	4
556	M	17.585	6.976	3	−95.3	−12.3	3	+72.7	+1.5	3
568	C	19.672	9.063	7	−68.1	+1.4	6	+57.9	+9.8	6
607	C	30.617	20.008	2	+20.4	−0.9	2	−45.2	−0.2	2
608	C	30.624	20.015	2	+21.1	−0.2	3	−51.3	−6.3	2
620	M	31.600	0.454	11	+30.0	−3.2	7	−52.7	−1.1	9
621	M	31.606	0.460	6	+37.7	−1.5	4	−65.6	−14.0	5
635	C	June 2.591	2.445	8	+35.1	−18.8	8	−63.2	+0.5	8
636	C	2.596	2.450	5	+46.0	−7.9	7	−64.6	−1.1	6
657	M	4.627	4.481	5	+39.2	−8.8	6	−72.0	−13.0	5
658	M	4.634	4.488	5	+30.9	−17.1	5	−66.0	−7.0	5
668	H	6.580	6.434	10	−66.9	+0.6	8	+53.0	−5.0	9
669	H	6.594	6.448	4	−63.9	+3.6	4	+55.1	−3.0	4
670	H	6.610	6.464	9	−65.1	+2.4	11	+58.2	+0.2	10
681	M	7.603	7.457	18	−88.2	−3.0	18	+73.1	+2.3	18
682	M	7.609	7.463	21	−80.4	−4.2	20	+71.6	+0.8	20
688	M	8.594	8.448	15	−77.7	−0.2	14	+54.6	−3.6	14
689	M	8.601	8.455	15	−72.6	+4.9	15	+61.5	+3.3	15
706	H	9.503	9.447	8	−58.8	+5.4	7	+43.6	+0.2	7

TABLE IV. VELOCITIES.

ANN ARBOR OBSERVATIONS—CONT'D.

PLA. NO.	OBS.	DATE G. M. T.		PHASE.	COMPONENT 1			COMPONENT 2			
					N	V	O–C	N	V	O–C	WT.
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11).
		1912									
707	H	June	9.606	9.460	6	—61.2	+ 3.0	6	+14.8	+ 1.4	6
718	C		10.617	10.471	5	—49.7	+ 1.6	5	+35.5	+ 5.3	5
719	C		10.639	10.493	7	—58.0	— 6.7	7	+24.3	— 5.9	7
731	M		11.617	11.471	6	—45.1	— 5.1	6	+ 9.2	—10.8	3
732	M		11.631	11.485	3	—42.7	— 2.8	3	+28.0	+ 7.8	3
749	M		21.669	0.987	6	+34.6	+ 9.1	5	—51.7	+ 3.6	5
750	M		21.677	0.995	6	+43.2	— 0.5	5	—66.1	—10.8	5
758	M		22.588	1.906	1	+46.1	— 4.2	1	—64.9	— 4.5	1
759	M		22.597	1.915	6	+47.7	— 2.6	7	—49.3	+11.1	6
773	M		28.619	7.937	2	—80.8	+ 2.2	2	+58.7	+ 3.9	2
774	M		28.624	7.942	4	—77.2	+ 5.0	4	+52.5	— 2.3	4
782	H		30.594	9.912	5	—64.4	+ 7.6	7	+45.3	+ 4.3	6
783	H		30.603	9.921	5	—64.2	+ 7.8	5	+43.5	+ 2.5	5
845	C	July	11.613	0.394	9	+33.1	— 6.1	10	—48.0	+ 3.5	9
846	C		11.625	0.406	7	+38.1	— 1.1	6	—62.2	—10.7	6
853	H		13.594	2.375	7	+62.0	+ 8.3	7	—69.9	— 6.7	4
854	H		13.608	2.389	5	+63.2	+ 9.5	5	—65.4	— 2.2	5
863	H		14.593	3.374	6	+37.7	—20.3	6	—73.2	— 5.7	6
864	H		14.606	3.387	8	+53.2	— 4.8	8	69.8	— 3.2	8
873	H		17.638	6.419	14	—69.5	— 3.0	14	+61.0	+ 3.9	14
884	H		18.588	7.369	10	—80.9	+ 4.3	10	+76.1	+ 4.1	10
887	C		18.648	7.429	4	—93.9	— 8.7	4	+56.5	—15.5	4
926	H		31.577	20.359	3	+31.6	— 2.9	3	—48.4	— 0.7	3
927	H		31.636	20.417	3	+35.1	+ 0.6	3	—43.9	+ 3.8	3
936	C	Aug.	1.600	0.845	7	+43.1	+ 0.6	7	—48.7	+ 5.6	7
939	C		2.591	1.836	8	+42.8	— 7.0	7	—60.5	— 0.3	7
940	H		2.501	1.846	11	+60.0	+10.2	11	—52.3	+ 7.9	11
941	H		2.623	1.868	9	+58.9	+ 9.1	9	—63.7	— 3.5	9
949	H		4.580	3.825	8	+70.5	+13.5	9	—58.8	+ 8.9	8
950	H		4.588	3.833	5	+66.5	+ 9.5	5	—66.9	+ 0.8	5
951	H		4.597	3.842	7	+67.2	+10.2	8	—64.8	+ 2.9	7
952	H		4.603	3.848	8	+58.7	+ 1.7	8	—72.7	— 5.0	8
959	H		11.584	10.829	4	—47.5	+ 0.2	5	+29.4	+ 2.6	4
999	H		21.565	0.273	5	+32.2	— 6.5	6	—53.8	— 2.8	5
1000	H		21.586	0.294	5	+45.0	+ 6.3	6	—47.5	+ 3.5	5
1009	C		22.623	1.331	3	+40.1	— 5.1	4	—62.7	— 6.7	3
1010	C		22.647	1.355	6	+50.0	+ 4.8	6	—52.6	+ 3.4	6
1015	C		23.565	2.273	10	+51.6	— 1.8	10	—67.6	— 4.6	10
1016	H		23.590	2.298	9	+60.9	+ 7.5	9	—65.8	— 2.8	9
1017	H		23.619	2.327	11	+52.6	— 0.8	11	—61.7	+ 1.3	11

TABLE IV. VELOCITIES.

ANN ARBOR OBSERVATIONS—CONT'D.

PLA. NO. (1)	OBS. (2)	DATE G. M. T. (3)	PHASE. (4)	COMPONENT 1 N (5)	V (6)	O–C (7)	COMPONENT 2 N (8)	V (9)	O–C (10)	WT. (11)
		1912								
1030	H	Aug. 27.567	6.275	6	−55.0	+5.2	6	+48.2	−2.1	6
1031	H	27.600	6.308	7	−58.2	+2.0	7	+46.4	−3.9	7
		1913								
2272	H	Aug. 29.597	3.650	17	+51.1	−6.1	18	−64.0	+2.0	17
2273	H	29.657	3.710	11	+60.5	+3.3	12	−66.1	−0.1	11
2274	H	29.662	3.715	11	+58.4	+1.2	10	−64.3	+1.7	10
2278	H	30.613	4.666	16	+44.3	+0.3	16	−54.5	+0.5	16
2279	H	30.639	4.692	14	+50.1	+6.6	15	−61.9	−6.9	14
2280	H	30.663	4.716	18	+47.7	+4.7	19	−58.5	−4.0	18
2281	H	30.675	4.728	14	+38.8	−3.7	14	−49.0	+5.0	14
2282	H	30.688	4.741	8	+31.9	−10.1	6	−41.0	+12.0	7

Normal Places. The data derived from plates showing the lines measurably separated will be discussed first. The observations were combined into sixteen normal places with phase as the basis of grouping. Care was taken that the limits of phase for each place be small enough for the velocity curves to be essentially straight over that interval. However, the correction for curvature was applied even though very small. The weight assigned was based on the number of measurable lines on all of the plates used in making up the normal place. The phases given in column (2) of Table VI are based on the final period and have been reduced to the sun. The values given in column (3) are the limits of phase within which all of the plates of that normal place fall. The velocities of the two components are given; also, the errors in the sense, observed minus computed, the final elements being used in determining the computed velocities.

The normal velocities, given in Table VI, are shown by the small circles as plotted in Plate VII.

Component 1. From the data of Table VI, a velocity curve was plotted and the following set of preliminary elements found.

PRELIMINARY ELEMENTS (COMPONENT 1).

$P = 20.53644$ days,
$\mu = 17^\circ.5298$,
$T = 5.83$ days from 1912, March 10.000,
$e = 0.5224$,
$\omega = 103^\circ\ 18'.2$,
$K = 72.85$ km.,
$V_0' = -13.35$ km.,
$\gamma = -4.1$ km.

An ephemeris having been computed and from it the residuals obtained, a least square solution was undertaken. The usual method of treatment gave the following

NORMAL EQUATIONS.

$$8.10\Gamma + 1.536\kappa - 0.485\pi - 0.185\epsilon + 0.659\tau + 5.332 = 0,$$
$$+ 6.101\kappa - 0.297\pi - 0.096\epsilon - 0.109\tau + 8.715 = 0,$$
$$+ 1.999\pi - 0.053\epsilon + 0.833\tau - 5.362 = 0,$$
$$+ 0.894\epsilon + 0.037\tau - 1.020 = 0,$$
$$+ 0.511\tau - 2.126 = 0.$$

TABLE V. VELOCITIES.

ANN ARBOR OBSERVATIONS.

PLATE NO.	OBS.	DATE G. M. T.		PHASE.	SINGLE LINES. N	V	RESIDUALS.	WT.
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
		1912						
377	C	Mar.	22.827	12.827	16	− 3.5	+ 3.8	16
378	C		22.833	12.833	21	− 3.5	+ 3.8	21
452	H	Apr.	15.724	16.188	21	− 8.4	− 1.1	21
453	H		15.733	16.197	23	− 5.9	+ 1.4	23
495	H	May	2.655	12.582	26	− 3.0	+ 4.3	26
496	H		2.661	12.588	23	− 8.1	− 0.8	23
512	M		7.681	17.608	17	+ 2.7	+ 10.0	17
513	M		7.687	17.614	11	− 5.9	+ 1.4	11
517	H		8.669	18.596	24	− 2.6	+ 4.7	24
518	H		8.678	18.605	19	− 13.4	− 6.1	19
573	H		22.666	12.057	23	− 9.1	− 1.8	23
574	H		22.676	12.067	27	− 16.7	− 9.4	27
580	M		24.680	14.071	24	− 12.5	− 5.2	24
581	M		24.686	14.077	22	− 11.2	− 3.9	22
595	M		25.742	15.133	16	− 1.4	+ 5.9	16
596	M		25.749	15.140	25	− 5.5	+ 1.8	25
602	C		27.642	17.033	23	− 8.5	− 1.2	23
603	C		27.652	17.043	23	− 7.9	− 0.6	23
734	H	June	12.646	12.500	15	− 4.4	+ 2.9	15
735	H		12.653	12.507	17	− 5.9	+ 1.4	17
763	M		25.588	4.906	5	− 8.8	− 1.5	5
807	H	July	3.649	12.967	18	− 10.3	− 3.0	18
808	H		3.677	12.995	22	− 1.8	+ 5.5	22
811	M		6.653	15.971	19	− 13.3	− 6.0	19
812	M		6.675	15.993	17	− 14.5	− 7.2	17
825	M		9.625	18.943	6	− 2.6	+ 4.7	6
826	M		9.635	18.953	5	− 4.5	+ 2.8	5
902	H		25.598	14.379	6	− 3.6	+ 3.7	6
903	H		25.628	14.409	11	− 12.7	− 5.4	11
911	M		27.610	16.391	16	− 6.2	+ 1.1	16
912	M		27.622	16.403	16	− 6.1	+ 1.2	16
918	C		29.624	18.405	7	− 6.0	+ 1.3	7
919	C		29.638	18.419	8	− 3.9	+ 3.4	8
972	H	Aug.	14.580	13.825	13	− 3.3	+ 4.0	13
973	H		14.603	13.848	14	− 13.6	− 6.3	14
1020	H		26.580	5.288	7	− 7.9	− 0.6	7
1021	H		26.611	5.319	7	− 2.3	+ 5.0	7
1022	H		26.647	5.355	6	− 0.5	+ 6.8	6

These equations gave the following values of the unknowns:

$$\tau = +1.048,$$
$$\epsilon = +1.009,$$
$$\pi = +2.004,$$
$$\kappa = -1.202,$$
$$\Gamma = +0.372.$$

That these results are correct was shown by the small residuals obtained when the values of the unknowns were substituted in the normal equations. The largest of the residuals was 0.005 and the average of the five was 0.003.

The normal equations having been satisfied, the corrections to the elements and the corrected elements were found to be:

CORRECTIONS.

$\delta K = -1.202$ km.,
$\delta\omega = -1° 34'.6$,
$\delta e = -0.00456$,
$\delta T = +0.01258$ days,
$\delta\gamma = -1.611$ km.

CORRECTED ELEMENTS (COMPONENT 1).

$K = 71.648$ km.,
$\omega = 101° 43'.6$,
$e = 0.51784$,
$T = 5.84258$ days from 1912, March 10.000,
$\gamma = -6.221$ km.

The residuals as found from the normal equations and from the ephemeris as computed from these corrected elements were in satisfactory agreement. In no case was the difference larger than 0.08 km., while the average value was slightly less than 0.04 km. From this, it was evident that the second order terms neglected in the least square formulæ were negligible and hence a second least square solution was unnecessary.

As in the preceding cases, the formula for $a \sin i$ was applied. The value follows:

$$a \sin i = 17{,}310{,}000 \text{ km.}$$

When Component 2 had been carried through to this point, it was possible to find the mass of

TABLE VI. NORMAL PLACES.

ANN ARBOR OBSERVATIONS.

NO.	PHASE.	LIMITS OF PHASE.	WT.	COMPONENT 1		COMPONENT 2	
				VELOCITY.	O–C.	VELOCITY.	O–C.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	6.380	6.26 to 6.47	0.75	−63.40	+1.05	+53.61	−0.97
2	6.784	6.63 to 6.98	0.65	−80.06	−0.73	+70.33	+1.72
3	7.440	7.36 to 7.47	0.66	−88.03	−2.68	+71.84	+0.99
4	8.327	7.93 to 8.46	0.60	−74.41	+3.84	+56.43	−3.38
5	9.545	9.06 to 9.93	0.38	−63.58	−0.66	+46.94	+4.68
6	10.570	10.47 to 10.83	0.20	−52.78	−2.24	+29.08	−0.37
7	11.479	11.47 to 11.49	0.04	−43.90	−3.35	+18.60	−0.94
8	20.050	19.80 to 20.42	0.08	+27.95	−3.79	−42.80	+2.66
9	20.853	20.55 to 21.00	0.62	+37.27	−0.86	−52.21	−1.43
10	21.539	21.29 to 21.90	0.43	+44.89	+1.32	−55.10	+0.14
11	22.400	22.37 to 22.45	0.43	+53.59	+3.45	−56.85	+3.69
12	22.889	22.80 to 22.99	0.67	+52.14	−1.35	−65.03	−1.83
13	23.337	23.32 to 23.35	0.20	+55.41	−0.62	−64.72	+0.45
14	24.156	23.91 to 24.26	0.85	+54.43	−3.32	−65.35	+0.94
15	24.427	24.36 to 24.53	0.54	+63.70	+7.01	−68.43	−3.14
16	25.194	24.91 to 25.28	1.00	+42.94	−0.99	−53.94	+0.15

each component in terms of i and the mass of the sun. For Component 1 we have

$$m_1 = \frac{1.83 \odot}{\sin^3 i}.$$

Bringing together the data which have been derived, we have the following

FINAL ELEMENTS (COMPONENT 1).

$$
\begin{aligned}
P &= 20.53644 \text{ days},\\
\mu &= 17^\circ.5298,\\
T &= 5.84258 \pm 0.07721 \text{ days from } 1912, \text{ March } 10.000,\\
e &= 0.51784 \pm 0.00812,\\
\omega &= 101^\circ\ 43'.6 \pm 2^\circ\ 24'.9,\\
K &= 71.65 \pm 0.69 \text{ km.},\\
\gamma &= -6.22 \text{ km.},\\
a \sin i &= 17{,}310{,}000 \text{ km.},\\
m_1 &= \frac{1.83 \odot}{\sin^3 i}.
\end{aligned}
$$

The probable errors of ω and T show about the same degree of uncertainty in the determination of these quantities as was found in the reduction of Ludendorff's measures. This was to have been expected since the quantity $[ee.4]$ almost vanished as before.

Points to be noted in connection with this curve and the corresponding elements are the following:

1. The sum of the weighted squares of the residuals was reduced by the least square solution from 90.86 to 62.04.

2. The probable error of a normal place of weight unity was found to be $\pm$ 1.60 km.

3. The residuals recorded in column (7) of Table IV were scaled from the velocity curve which was plotted from an ephemeris based on the final elements. See Plate VII. From these residuals, the probable error of an average plate was found to be $\pm$ 4.6 km. and that of the best plates of the series was found to be $\pm$ 2.8 km.

Component 2. From the data of Table VI, a velocity curve was plotted and the following set of preliminary elements found for Component 2.

PRELIMINARY ELEMENTS (COMPONENT 2)

$$
\begin{aligned}
P &= 20.53644 \text{ days},\\
\mu &= 17^\circ.5298,\\
T &= 5.88 \text{ days from } 1912, \text{ March } 10.000,\\
e &= 0.5420,\\
\omega &= 287^\circ\ 14'.6,\\
K &= 70.00 \text{ km.},\\
V_0' &= +2.60 \text{ km.},\\
\gamma &= -8.62 \text{ km.}
\end{aligned}
$$

By means of an ephemeris from these elements, the residuals were found for use in a least square solution. The sixteen equations of condition gave the following normal equations:

NORMAL EQUATIONS.

$$
\begin{aligned}
8.101\Gamma - 1.630\kappa + 0.681\pi + 0.399\epsilon - 0.538\tau + 2.287 &= 0,\\
+ 6.131\kappa - 0.831\pi - 0.028\epsilon - 0.071\tau + 3.942 &= 0,\\
+ 1.959\pi + 0.037\epsilon + 0.746\tau - 1.458 &= 0,\\
+ 0.864\epsilon + 0.054\tau + 0.196 &= 0.\\
+ 0.434\tau - 1.102 &= 0.
\end{aligned}
$$

A solution of these equations gave the values of the unknowns:

$$
\begin{aligned}
\tau &= +5.672,\\
\epsilon &= -0.587,\\
\pi &= -1.770,\\
\kappa &= -0.791,\\
\Gamma &= +0.113.
\end{aligned}
$$

The usual test for accuracy in the computation was applied and satisfactory agreement found, the largest residual being 0.008 and the average of the five, 0.004. The corrections and the corrected elements follow:

CORRECTIONS.

$$
\begin{aligned}
\delta K &= -0.791 \text{ km.},\\
\delta\omega &= +1^\circ\ 27'.9,\\
\delta e &= +0.00268,\\
\delta T &= +0.06611 \text{ days},\\
\delta\gamma &= -0.732 \text{ km.}
\end{aligned}
$$

CORRECTED ELEMENTS (COMPONENT 2).

$$
\begin{aligned}
K &= 69.209 \text{ km.},\\
\omega &= 288^\circ\ 42'.5,\\
e &= 0.54468,\\
T &= 5.94611 \text{ days from } 1912, \text{ March } 10.000,\\
\gamma &= -9.352 \text{ km.}
\end{aligned}
$$

In only one case did the difference between the residuals as given by the normal equations and by the ephemeris exceed 0.1 km. and the value in that case was only 0.12 km. The average value of the sixteen differences was less than 0.04. A second least square solution was considered unnecessary, since it would yield no changes of importance.

As in the preceding cases, the value of the quantity $a \sin i$ was found.

$$a \sin i = 16{,}390{,}000 \text{ km.}$$

The formulæ for finding the masses were applied with the following results:

$$m_1 = \frac{1.83 \odot}{\sin^3 i},$$

$$m_2 = \frac{1.79 \odot}{\sin^3 i}.$$

A comparison of the two masses gives the following value for their ratio:

$$\frac{m_1}{m_2} = 1.025.$$

Bringing together the data concerning Component 2, we have the following

FINAL ELEMENTS (COMPONENT 2).

$$P = 20.53644 \text{ days},$$
$$\mu = 17^\circ.5298,$$
$$T = 5.94611 \pm 0.05825 \text{ days from 1912, March 10.000},$$
$$e = 0.54468 \pm 0.00681,$$
$$\omega = 288^\circ\ 42'.5 \pm 1^\circ\ 58'.6,$$
$$K = 69.21 \pm 0.56 \text{ km.},$$
$$\gamma = -9.352 \text{ km.},$$
$$a \sin i = 16{,}390{,}000 \text{ km.},$$
$$m_2 = \frac{1.79 \odot}{\sin^3 i},$$
$$\frac{m_1}{m_2} = 1.025.$$

In connection with these elements and the corresponding velocity curve, the following points are of interest:

1. The sum of the weighted squares of the residuals was reduced from 41.41 to 40.92. The amount of this reduction is inconsiderable, but the fact should be noted that the sum of the weighted squares from the preliminary elements was less than the final sum after the application of the method of least squares in each of the other cases, indicating that the preliminary elements in this case satisfied the observed velocities exceptionally well.

2. The probable error of a normal place of weight unity was found to be $\pm$ 1.30 km.

3. The residuals recorded in column (10) of Table IV were scaled from the final velocity curve as plotted from the corrected elements. See Plate VII. From these residuals the probable error of the average plate was found to be $\pm$ 4.2 km., while that of the best plates of the series was $\pm$ 2.5 km.

Velocity curves. The velocity curves shown in Plate VII were plotted from an ephemeris computed from the final elements for each of the two components as derived from the Ann Arbor measures. Points were located at frequent intervals throughout the entire length of the curves so that they might give an accurate representation of the velocities in all parts of the orbits. Beginning at the left border of Plate VII, the upper curve belongs to Component 1 and the lower curve to Component 2.

Ratio of the masses and the center of mass velocity. Since there was an apparent lack of agreement between the values determined for each of these quantities and since Ludendorff found a difference in the values as determined at different epochs, it seemed desirable to give these elements further consideration. A formula is easily derived which gives a mathematical relation between the following quantities:

V_1 = a velocity for component 1,
V_2 = the corresponding velocity for component 2,
γ' = an assumed value for the center of mass velocity,
$\Delta\gamma$ = correction to be applied to the assumed center of mass velocity,
$\gamma = \gamma' + \Delta\gamma$,
$\frac{m_1}{m_2} = 1 + x$, defines the quantity, x.

If the assumed value of the center of mass velocity be near the true value and if the ratio of the masses be not far from unity, then $\Delta\gamma$ and x

are both small quantities. These conditions were both satisfied in the case under consideration. The formula follows and is exact except for the omission of the second order term, $\frac{1}{2}x \,.\, \Delta\gamma$ which may be neglected without appreciable error.

$$\Delta\gamma - \tfrac{1}{2}(V_1 - \gamma') \,.\, x = \tfrac{1}{2}(V_1 + V_2) - \gamma'.^*$$

Ann Arbor velocities. γ' having been assumed as —7.50 km., each pair of corresponding velocities when substituted in the equation gave an equation of condition. By the usual process these sixteen equations of condition were reduced to two normal equations with $\Delta\gamma$ and x as the unknowns. From a solution of the normal equations, the following values were found:

$$x = +0.032 \pm 0.011,$$
$$\Delta\gamma = +1.44 \pm 0.35 \text{ km.}$$

From which were obtained the ratio of the masses and the center of mass velocity:

$$\gamma = -6.06 \pm 0.35 \text{ km.},$$

$$\frac{m_1}{m_2} = 1.032 \pm 0.011.$$

The equation given above is not symmetrical in V_1 and V_2 as is evident from the left member. The analogous equation was derived and applied, giving results in agreement with the values just found.

At this point, it should be noted that this value of γ is less than 1 km. different from the mean of the velocities obtained from nearly a hundred spectrograms of ζ_2 Ursæ Majoris, as measured and reduced by the writer.

Potsdam velocities. A like solution was made using the normal velocities derived from the Ludendorff measures. The following results were obtained which are in close agreement with Ludendorff's determination of these same quantities as previously given in this paper:

$$\gamma = -12.55 \pm 0.58 \text{ km.},$$

$$\frac{m_1}{m_2} = 1.001 \pm 0.021.$$

This value of $\frac{m_1}{m_2}$ and its probable error throw some light on the fact that Ludendorff found from a part of his observations that the relative order of magnitude of this pair seemed to be reversed.

At this point it should be noted that there is less than 0.1 km. difference between this value of γ and the mean of the velocities obtained by Ludendorff for ζ_2 Ursæ Majoris.

Measures of plates showing single lines. These plates were measured and reduced with the same care as the plates showing the lines measurably separated. There were thirty-eight such spectrograms. In cases of this kind the measurement is that of the blends of the two sets of spectral lines. In case one spectrum had been decidedly stronger than the other, the fact should have revealed itself by an inclination of the line connecting the normal places formed from these velocities. No such inclination is evident, indicating that the spectra are of practically the same intensity. The apparent difference in the relative intensity of the spectral lines of the two components as noted by Miss Maury in the *Astrophysical Journal*, Vol. 8, page 174, was not observed in the measurement of the spectrograms made at this Observatory. The plates secured for the cross point at the steepest part of the curves were too few to give a good determination. However, the weights assigned to each of the other four normal places show the determinations to be of considerable importance in that they should give, theoretically, the center of mass velocity. The weighted mean of the last four normal places is —7.26 km.

The measures from the single line plates as combined into normal places are given below. The table shows the phase, limits of phase, weight, velocity and residual. These normal velocities are shown by the small dotted circles in Plate VII.

SUMMARY OF RESULTS

That a comparison of the elements may be made and the differences which occur may be clearly evident, the data concerning each component as found from both sets of measures are brought together. Rather unexpected differences in the values of some of the elements are found. These apparent discrepancies will be discussed later.

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* *Publications of the Allegheny Observatory*, Vol. 1, No. 22, page 175.

TABLE VII. VELOCITIES.

(FROM MEASURES OF SINGLE LINES.)

ANN ARBOR OBSERVATIONS

NO	PHASE.	LIMITS OF PHASE.	WT.	SINGLE LINES. VELOCITY.	RESIDUAL.
(1)	(2)	(3)	(4)	(5)	(6)
1	5.523	4.90 to 5.36	10	−4.92	+2.34
2	12.564	12.05 to 13.00	82	−6.99	+0.27
3	14.388	13.82 to 15.14	52	−8.56	−1.30
4	16.458	15.97 to 17.05	58	−8.56	−1.30
5	18.458	17.60 to 18.95	33	−5.48	+1.78

CORRECTED ELEMENTS OF COMPONENT 1.

	LUDENDORFF.	HADLEY.
$P =$	20.53644 days,	20.53644 days,
$\mu =$	17°.5298,	17°.5298,
$T =$	5.6058 ± 0.0700 days,*	5.8426 ± 0.0772 days,*
$e =$	0.5315 ± 0.0102,	0.5178 ± 0.0081,
$\omega =$	103° 52′.2 ± 2° 47′.9,	101° 43′.6 ± 2° 24′.9,
$K =$	66.05 ± 0.77 km.,	71.65 ± 0.69 km.,
$\gamma =$	−11.67 km.,	−6.22 km.,
$a \sin i =$	15,800,000 km.,	17,310,000 km.,
$m_1 =$	$\frac{1.57 \odot}{\sin^3 i}$.	$\frac{1.83 \odot}{\sin^3 i}$.

* From 1912, March 10.000.

CORRECTED ELEMENTS OF COMPONENT 2.

$P =$	20.53644 days,	20.53644 days,
$\mu =$	17°.5298,	17°.5298,
$T =$	5.4515 ± 0.0835 days,*	5.9461 ± 0.0582 days,*
$e =$	0.5533 ± 0.0124,	0.5447 ± 0.0068 days,
$\omega =$	276° 55′.8 ± 2° 17′.5,	288° 42′.5 ± 1° 58′.6,
$K =$	67.76 ± 0.98 km.,	69.21 ± 0.56 km.,
$\gamma =$	−11.96 km.,	−9.35 km.,
$a \sin i =$	15,940,000 km.,	16,390,000 km.,
$m_2 =$	$\frac{1.46 \odot}{\sin^3 i}$,	$\frac{1.79 \odot}{\sin^3 i}$,
$\frac{m_1}{m_2} =$	1.079.	1.025.

* From 1912, March 10.000.

A comparison of the four sets of elements is both interesting and instructive. The differences between the values of certain of the quantities is greater than the probable errors would lead one to expect. It seemed advisable to derive the elements in this way so that such differences as do occur may be clearly evident. These differences in no way discount the accuracy of the elements of such an orbit in so far as they are to represent the observations, but they do raise the question as to whether the observations give the exact conditions of motion as they exist in the binary system. However, as has been pointed out, the measures in this case were difficult.

The discrepancies between the four sets of elements, which have been tabulated, may be divided into two classes: those between the elements for the two components at the same epoch and those between the elements of the same component at different epochs.

Relatively large differences of both kinds were to be expected in the case of this star on account of the limitations imposed by the character of the spectra and by the existence of two components for each line when relative motion was sufficiently great to produce separation. Vogel has called attention to the poor quality of the lines from the standpoint of measurability. However, his conclusions are not surprising. In general, when resolved, each line of the star's spectrum falls upon the continuous spectrum of the other star and thus cannot present a clearly defined interruption. In other cases, a line of one spectrum might also coincide with a very faint line of the other spectrum and thus render the measure defective. Further, during about half of each orbital cycle the relative motion of the two components was too small to cause complete separa-

tion of the lines, hence the measures under those conditions were of uncertain value. From a consideration of these facts it becomes very evident that the available data for the determination of elements is unavoidably limited in this case.

In a system of this character, with high orbital eccentricity and relatively close approach of the two bodies at periastron, there would be strong probability that librations and tidal disturbances would arise to such an extent that they would produce irregularities in the velocity curves. These irregularities in the velocity curves would in turn give rise to spurious differences in the elements of the two orbits. Irregularities, which are probably of this nature, have been observed in highly eccentric orbits with relatively short periods, such as θ Aquilæ and ψ Orionis. The great variation in the rate of anomalistic motion as the bodies pass from apastron to periastron in very eccentric orbits suggests at once a cause for at least a part of the apparent lack of consistency in the results.

An examination of the original papers discussing binaries with highly eccentric orbits shows clearly that the difficulties which have been encountered in the study of this star are not peculiar to it alone. The writer has examined with some care the papers dealing with thirty-three orbits whose eccentricities exceed 0.3, the average value being 0.498. While it is difficult, if not impossible, to determine what precision may be expected in such work, it is the opinion of the writer that not less than two-thirds of the cases examined show some peculiarity. In six cases secondary oscillations had been assumed in order to reduce the differences between observed and computed velocities. In many other cases a like treatment would undoubtedly have reduced the residuals. At least half of the cases examined show more or less marked indications of a secondary oscillation. Other cases showed unexpectedly large residuals. It seems more reasonable to attribute these irregularities in the observed velocities either directly or indirectly to the high eccentricity than it does to assume the presence of a small third body. There is no reason to believe that the presence of a small third body tends to produce a highly eccentric orbit. Visual observations have rarely revealed three-body systems, indicating that they are few in number. It seems to be a reasonable supposition that the same is true of systems less widely separated which can be revealed only by spectroscopic methods of observing. Hence, it seems more to the point to attribute slight departures from elliptic motion to tidal disturbances present in highly eccentric orbits.

In this connection, attention should be called to two sets of elements as derived from θ Aquilæ by Baker and Harper. A discussion of the elements of the orbit of this binary is to be found in the *Publications of the Royal Astronomical Society of Canada*, Vol. III, page 95. The difference in time for the two sets of observations is too small for the elements to have suffered appreciable change. The lack of agreement between the values as determined for certain elements is of the same order as has been found in the study of ζ_1 Ursæ Majoris. In both cases the probable errors indicate that the elements as derived satisfy the observations well, but the differences between the two sets of elements for the same star seem to show that the actual conditions of motion in the orbit are not obtained with as great precision as the probable errors of a single set of elements indicate.

A careful examination of the two plates showing the velocity curves for ζ_1 Ursæ Majoris reveals irregularities which can hardly be attributed to accidental errors. The many cases in which the observed velocities for the two sets of measures at approximately the same phase are either both larger or both smaller than the corresponding computed velocities is striking. The frequency with which this occurs is convincing evidence of its reality even though the real cause can not be definitely stated.

Apparently real irregularities existing in the velocity curves of stars of certain classes may place a limit on the accuracy of our determination of their orbital elements. The discrepancies observed in this paper furnish some evidence as to the uncertainty which may come from such irregularities and in that connection are highly instructive.

An effort was made to combine the four sets of elements, first, using the elements from the

two components at the same epoch, and then using these elements in securing the final values.

Elements from the Potsdam Observations. In bringing together the values of the elements as derived from the two components and also from the two sets of observations, weights will be assigned which are inversely proportional to the squares of the probable errors of the different determinations.

Nothing further need be said concerning the values of P and μ.

Evidently, the two values of T cannot be different since the two stars of the system must both have the same time for periastron passage; hence, the weighted mean will be taken as the best value for this quantity.

In connection with the value of e, it is of interest to note that the eccentricity of the orbit of Component 2 is the larger for both sets of measures. The weighted mean will be accepted as the best determination of this quantity since the two orbits cannot differ in this respect.

The two values of ω should differ by 180°. The best value of ω for Component 1 is probably given by taking the weighted mean of the two after 180° has been subtracted from the value of ω for Component 2.

The values of K for the two components are not very different. Only a small difference would be expected for a system in which $\frac{m_1}{m_2}$ is nearly equal to unity, as it is in this case.

Values for the ratio of the masses and for the center of mass velocity were obtained from the least square solution along with the other elements. The values of these two quantities alone were determined from other considerations by a least square solution. The means of these values will be taken as the most probable values of γ and $\frac{m_1}{m_2}$.

The two values for $a \sin i$ should not be the same unless the ratio of the masses be unity, which it is not. However, the difference should be small in the case of this star.

Elements from Ann Arbor Observations. The treatment will be like that of the Potsdam observations, the one exception being in connection with the center of mass velocity. A determination of the velocity of the center of mass was obtained from the plates showing single lines as has been mentioned already. The precision of this method is less than that of the other methods, hence, the weight assigned to the result will be only half as great as that of the other determinations.

It should be noted at this point that the value of $a \sin i$ is larger for Component 1 than for Component 2, whereas m_1 is greater than m_2. The explanation is to be found in the fact that the two velocity curves as plotted from the normal velocities gave different values for the eccentricity. In the case of the Potsdam elements, the value of $a \sin i$ for Component 2 is the larger; however, it is only slightly larger, the difference being less than the value of $\frac{m_1}{m_2}$ would lead one to expect.

The elements of the two components for each set of observations having been combined in the manner set forth, the following sets of elements are given as the result of that process:

POTSDAM OBSERVATIONS.

$$P = 20.53644 \text{ days},$$
$$\mu = 17°.5298,$$
$$T = 5.5356 \pm 0.0546 \text{ days},^*$$
$$e = 0.54058 \pm 0.00805,$$
$$\omega = 99° 39'.3 \pm 1° 50'.9,$$
$$K_1 = 66.05 \pm 0.77 \text{ km.},$$
$$K_2 = 67.76 \pm 0.98 \text{ km.},$$
$$\gamma = -12.06 \text{ km.},$$
$$m_1 = \frac{1.57 \odot}{\sin^3 i},$$
$$m_2 = \frac{1.46 \odot}{\sin^3 i},$$
$$\frac{m_1}{m_2} = 1.038,$$
$$a_1 \sin i = 15{,}800{,}000 \text{ km.}$$
$$a_2 \sin i = 15{,}940{,}000 \text{ km.}$$

* From 1912, March 10.000 G. M. T.

ANN ARBOR OBSERVATIONS.

$P = 20.53644$ days,
$\mu = 17^\circ.5298$,
$T = 5.0088 \pm 0.0483$ days,*
$e = 0.53248 \pm 0.00530$,
$\omega = 105^\circ 35'.9 \pm 1^\circ 33'.8$,
$K_1 = 71.65 \pm 0.60$ km.,
$K_2 = 69.21 \pm 0.56$ km.,
$\gamma = -7.22$ km.,

$$m_1 = \frac{1.83 \odot}{\sin^3 i},$$

$$m_2 = \frac{1.79 \odot}{\sin^3 i},$$

$$\frac{m_1}{m_2} = 1.027,$$

$a_1 \sin i = 17{,}310{,}000$ km.,
$a_2 \sin i = 16{,}390{,}000$ km.

* From 1912, March 10.000, G. M. T.

CONCLUSIONS.

By combining the two sets of elements in the same manner as were the elements of the two components for one set of observations, we obtain the following as the most probable values and announce them as the definitive elements of ζ_1 Ursæ Majoris:

DEFINITIVE ELEMENTS.

$P = 20.53644$ days,
$\mu = 17^\circ.5298$,
$T = 1912$, March. 15.7440 ± 0.0364 days, G. M. T.,
$e = 0.53476 \pm 0.00482$,
$\omega = 103^\circ 57'.5 \pm 1^\circ 12'.4$,
$K_1 = 69.22 \pm 0.52$ km.,
$K_2 = 68.83 \pm 0.56$ km.,
$\gamma = -9.64$ km.,

$$m_1 = \frac{1.70 \odot}{\sin^3 i},$$

$$m_2 = \frac{1.62 \odot}{\sin^3 i},$$

$$\frac{m_1}{m_2} = 1.032,$$

$a_1 \sin i = 16.4$ million km.,
$a_2 \sin i = 16.4$ million km.

There has been no marked change in the spectrum of the star so far as the writer was able to judge.

The small difference in the position of the line of nodes is not thought to be real. It is probably to be attributed to the peculiarities of the velocity curve, the positions of the normal places, and to personal equation.

An appreciable change in the eccentricity is improbable and the difference for the two components cannot be real so far as the actual orbits are concerned.

The values of the K's for the two sets of observations are in fair agreement. No real change in these quantities is probable in so brief a period of years. Personal equation and choice of spectral lines would account for a part, if not all, of the difference. The half-amplitude of the velocity curve for Component 1 is slightly larger than it is for Component 2, whereas m_1 is greater than m_2. This is due to peculiarities of the curves and the close approach of the ratio of the masses to unity.

The velocity of the center of mass of ζ_1 Ursæ Majoris and the mean velocities of ζ_2 Ursæ Majoris as determined from the Potsdam measures are in close agreement. The same is true of the Ann Arbor observations. It follows that the difference between the Potsdam and Ann Arbor values of γ for ζ_1 Ursæ Majoris is approximately equal to the difference in the mean velocity of ζ_2 Ursæ Majoris as determined at these two observatories. That each of the two stars should have a variable center of mass velocity and that the changes should be almost the same in magnitude and of the same sign seems to be an unreasonable assumption. Hence the writer has been led to the conclusion that the apparent change in γ for ζ_1 Ursæ Majoris is not real, but that it is due to systematic differences attributable to personal equation and other causes. The difference in this quantity noticed by Ludendorff as mentioned early in this paper may be explained by the fact that the parts of the spectrum used by Ludendorff in the two groups of plates were not identical.

The masses of the two components are nearly equal, but a summary of the data bearing on this

point indicates that one component is approximately three per cent. larger than the other.

The determinations of $a \sin i$ for the two components are somewhat uncertain, but are of nearly equal value. Probably 16.4 million km. for each component is as definite as the data warrant.

The positions of the normal places as shown in connection with the velocity curves plotted from the final elements indicate the presence of a disturbing factor. The reality of these irregularities is shown by the fact that in many cases the residuals for the normal places of practically the same phase for the two components are of the same sign. A secondary oscillation suggests itself. However, the unavoidable lack of data in this case covering nearly half of the length of the curves makes the study of such an oscillation very difficult. The examination of many orbits of high eccentricity has led the writer to the conclusion that irregularities are the rule in such cases rather than the exception, and that they are attributable directly or indirectly to the high eccentricity.

While the probable errors seem to show the precision with which the derived elements represent the observed velocities, they do not show the precision with which the elements represent the actual conditions of motion of the star in its orbit.

The generally accepted theory as to the mutual increase of eccentricity and period seems to be sustained by the values of these two quantities as found in connection with this spectroscopic pair.

If the views as expressed by Wicksell in his paper entitled "Contributions to the Statistics of Spectroscopic Binary Stars" be correct, then this star would seem to belong to the class consisting of those binaries which have originated through fission rather than through the "capture process". The length of the period and the high eccentricity indicate that the existence of this star as a binary has been of long duration even though the spectral types of the two components show that they have not progressed very far in their evolutionary course.

The writer wishes to express his thanks to Professor Ralph H. Curtiss whose counsel, direction, and assistance have made this investigation possible. A word of appreciation is due Mr. Lewis Mellor of this Observatory for assistance in making plates.

Ann Arbor, Michigan, May, 1915.

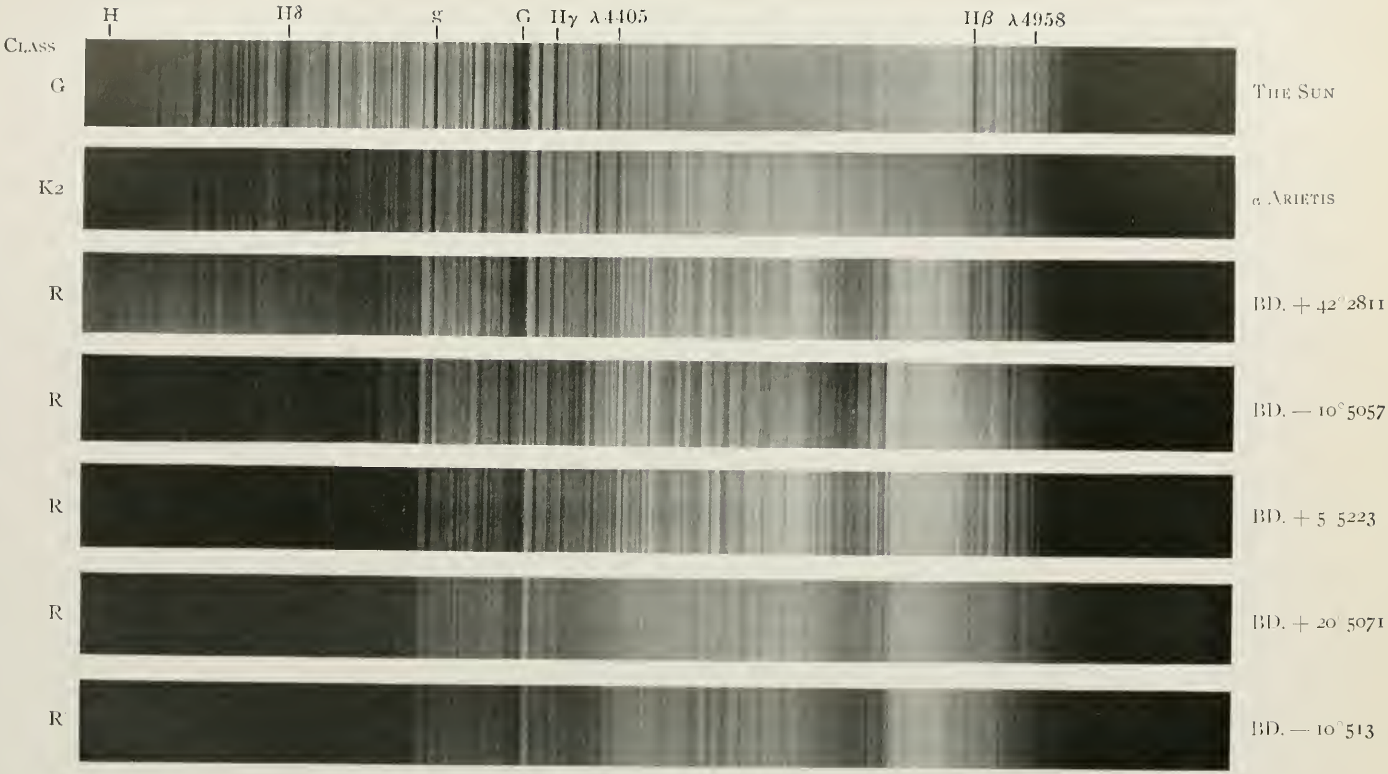

Plate G. Class G, Class K2 and Earlier Class R Stellar Spectra Compared

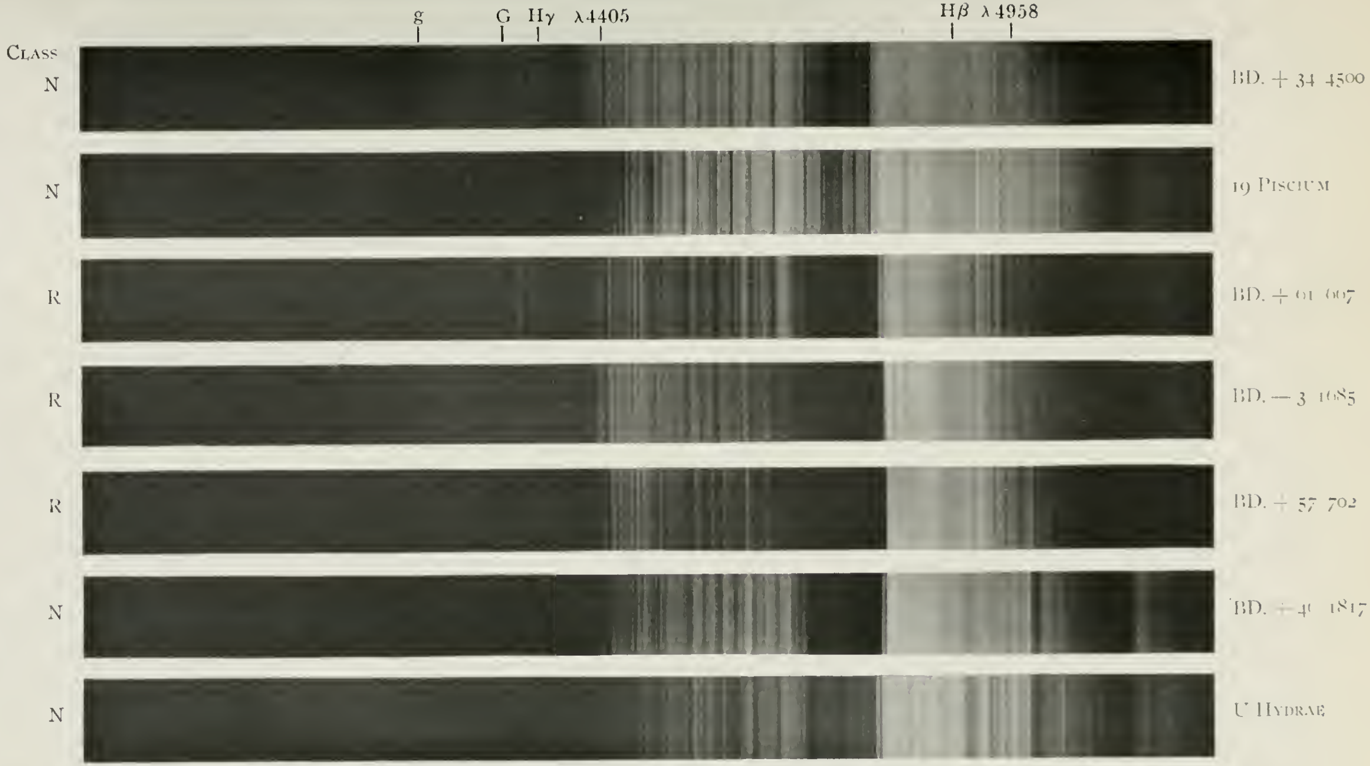

Plate II. Class N and Late Class R Stellar Spectra in the Photographic Region

AN INVESTIGATION OF THE SPECTRA OF STARS BELONGING TO CLASS R OF THE DRAPER CLASSIFICATION[1]

By W. CARL RUFUS

INTRODUCTION

The genesis of Class R of the Draper Classification of stellar spectra may be traced from a list of "Stars Having Peculiar Spectra," published in *Harvard College Observatory Circular*, No. 9, July 9, 1896. Following the table is the statement: "Of the seven stars whose spectra are here announced as of Type IV the first, second, and seventh[2] (fourth), are normal. The spectra of others contain rays of much shorter wave-length than ordinary fourth type stars." This is a characteristic feature of the spectra of stars later designated as Class R and is here attributed to four stars, DM. — 38° 12843, + 85° 332, — 12° 5755, and + 5° 5223. Two other stars of the list, DM. — 31° 15954 and — 29° 15574, whose spectra were described as peculiar, but not associated with the four previously mentioned, have also been assigned to this class. These six stars constitute the nucleus of Class R.

Later announcements of stars having peculiar spectra increased the number possessing the common characteristics, "rays of shorter wave-lengths than the ordinary fourth type stars," and "a strong band extending from about λ 461 $\mu\mu$ to λ 471 $\mu\mu$." These stars were frequently referred to as belonging to "the same class as Z.C. 10^h 2112 described above", or "the same type as C.D.M. — 47° 6614, described in *Circular*, No. 76." A more convenient method of reference seemed to warrant the addition of a new class, which was suggested by Professor Pickering in *Harvard Circular*, No. 145, "A Sixth Type of Stellar Spectra," published December 1, 1908. A table of "Stars Having Spectra of Class R," containing sixty-one stars is given in *Harvard Annals*, Volume 56, page 220. A few others are known. In order to complete the list to date Table I is appended. The successive columns give the star's designation, right ascension and declination for 1900, Durchmusterung magnitude, Harvard photometric magnitude, galactic longitude and latitude, date of discovery, name of discoverer, and reference concerning announcement.

PURPOSE OF THIS INVESTIGATION

1. We propose to study the relationship between the spectra of stars of Class R and stars of Class N.

That a close relationship exists is evident from the fact that many Class R stars were announced

[1] A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

[2] In a letter dated February 11, 1915, Professor E. C. Pickering says: "In *Harvard Circular* 9, the word 'fourth' should be substituted for 'seventh' in the passage you quote."

TABLE I. STARS WITH SPECTRA OF CLASS R NOT INCLUDED IN TABLE XI, PAGE 220, VOLUME 56, ANNALS OF THE HARVARD COLLEGE OBSERVATORY.

STAR.	R. A. 1900.	DECL. 1900.	MAGNITUDE.		GALACTIC		DATE.	DISCOVERER	REFERENCE.
			D. M.	H. P.	LONG.	LAT.			
+ 23°123	0^{h}48^m.9	+ 23°32′	8.3	8.8	91°	— 32°	1914	Cannon	H. C. 184
+ 14 1598	7 7 .2	+ 14 46	Var.	9.2	171	+ 12	1914	Cannon	H. C. 184
— 14 4371	16 7 .6	— 14 57	9.5	...	326	+ 24	1910	Fleming	H. C. 158
+ 42 2811	17 10 .4	+ 42 15	7.3	7.74	37	+ 34	1914	Cannon	H. C. 184
Uncertain	17 33 .5	— 57 52	...	...	302	— 15	1901	Fleming	H. C. 60 H. A. 56, 223
— 3 5751	23 57 .0	— 3 23	9.2	9.9	63	— 64	1914	Cannon	H. C. 184

as having a spectrum of Type IV (N), or resembling Type IV with peculiarities (N_p). Parkhurst expresses this condition by stating, "No sharp line can be drawn between Classes N and R."[3]

2. We propose also to study the relationship between stars of Classes R and N on the one hand and stars of the Harvard sequence (B, A, F, G, K, M) on the other.

Concerning stars of the fourth type Miss Clerke says:[4] "They have indeed traceable relationships; but the genealogy obscurely indicated by them needs authentication." Vogel in 1874 proposed that Secchi's Types III (Harvard K, M) and IV (Harvard R?, N) be considered in one class and designated as IIIa and IIIb. Hale, Ellerman, and Parkhurst in a valuable treatise on "The Spectra of Stars of Secchi's Fourth Type"[5] reached the conclusion: "Stars of the third and fourth types should therefore be classed together, as coordinate branches leading back to stars like the sun."

Pickering, in the letter previously referred to, says: "We have not been able to establish the sequence between classes M and R. Owing to the intensity of the blue light and the presence of lines H and K in stars of Class R, it seems more probable that Class R should fall between M and N."

In particular the thesis is proposed: Stars belonging to Class R of the Draper Classification of stellar spectra form the connecting links between stars of the solar type (G) and stars of Class N; and stars of the two classes, R and N, form a branch of the sequence arranged in order of stellar evolution coordinate with the branch consisting of stars of Classes K and M.

Furthermore, it is hoped that the quantitative and qualitative data obtained during this investigation will contribute in some measure to the broader problem of stellar evolution in general.

GENERAL CHARACTERISTICS

The table of Class R stars contains 66 members, none of which is brighter than the seventh visual magnitude. Among the number whose magnitude is given there are:

VISUAL MAGNITUDE.	TOTAL NUMBER.	NORTH OF — 20°.
7.0 to 7.9	7	5
8.0 to 8.9	13	8
9.0 to 9.9	30	13
10.0 to 10.9	6	0

Five are marked as having a variable magnitude. Only twenty are in the northern hemisphere. Not as great preference seems to be given for the galactic region as in the case of Classes N, B, and O.

The following table, showing the distribution of stars of various spectral classes with reference to the Galaxy, is based upon the work at Harvard[6] as summarized by Russell[7] with the data for Class R stars added by the writer. The count for Class R was made for the region + 30° to — 30° galactic latitude. The Harvard count for the other classes varied from these limits in different regions on account of the irregularity of the Galaxy.

Class	O	B	A	F	G	K	M	R	N
Percentage in Galactic Region	100	82	66	57	58	56	54	63	87

The color of Class R stars has been referred to as "probably yellow like the stars of the second type."[8] This characteristic is suggested as one of the features distinguishing stars of Class R from those of Class N:[9] "Stars having spectra of the fourth type are commonly regarded as red stars;" which indicates that the Harvard observers considered that, in general, stars of Class R are not red. Miss Clerke referred to two of the number as "white stars"[10] — 10° 5057 and — 10° 513.

[3] The Spectra and Colors of Red Stars of Harvard Classes N and R. *Astrophysical Journal*, Vol. 35, p. 125.

[4] *Problems in Astrophysics*, p. 215.

[5] *Publications of the Yerkes Observatory*, Vol. 2 p. 385, 1903.

[6] *Harvard Annals*, Vol. 64, p. 134.

[7] *Publications American Astronomical Society*, Sixteenth Meeting, p. 26.

[8] *Harvard Annals*, Vol. 56, p. 219.

[9] *Harvard Circular*, 145, p. 3.

[10] *Problems in Astrophysics*, p. 221.

Parkhurst has determined the color index of five stars of the list as follows:

STAR.	COLOR INDEX.
— 10° 5057	1.09
+ 85 332	1.56
+ 53 66	1.66
+ 20 5071	1.82
+ 6 3808	2.37

Compared with his results for the color index of nine stars classed as N and Na (1.94 to 3.26) it appears that in general stars of Class R are not as red as those of Class N. He reaches the conclusion, however, that the expression "Fourth-Type Stars not Red," seems inappropriate;[11] and he apparently includes Class R stars in the expression, Fourth-Type Stars.

The difference in color between stars of these classes (N and R) as seen by visual observers may be tested by referring to any catalogue of red stars. Birmingham-Espin's catalogue of 766 red stars contains only two out of twenty stars of Class R from the seventh to the ninth magnitude, DM. + 61° 667 and — 3° 1685; while it catalogues seventy per cent. of the stars of Class N within the same range of magnitude. The difference in color between the two classes was clearly discernible during our observations, forming a gradual transition from Class R to Class N with increasing redness.

The following table is inserted to show the change in color index with spectral type. It gives the mean of the values obtained by different observers and tabulated by Russell.[12] The value for Class R has been added by the writer.

The general characteristics of the spectra of stars of Class R are given in the various circulars previously referred to and include:

1. Rays of much shorter wave-length than ordinary fourth-type stars.

2. The blue end is no longer cut off but extends to as short a wave-length as in spectra of Class K.

3. The lines H and K are well shown.

4. One or more dark bands, resembling the spectrum of the fifth type reversed on a continuous spectrum.

5. Two well-marked absorption bands, one of which has a center near the calcium line λ 4227, the other extending from λ 4640 to λ 4750.

COLOR INDICES OF STARS BY SPECTRAL TYPES.

CLASS OF SPECTRUM.	AVERAGE COLOR INDEX.
B 0	—0.32
B 5	—0.19
A 0	0.00
A 5	0.00
F 0	0.38
F 5	0.58
G 0	0.80
G 5	1.02
K 0	1.27
K 5	1.64
M	1.65
R	1.7
N	2.5

Further indication of the relation of these spectra to others is found in the following remarks:

1. "It appears probable that stars can be found forming a continuous sequence from Class N to Class R, like that connecting Class B and Class M." *Harvard Annals,* Vol. 56, p. 220.

2. The designation N5R is applied to three stars of intermediate type listed in "Stars of Class N." *Harvard Annals,* Vol 56, p. 219, Remark 5.

The order of the sequence *from* Class N *to* Class R suggested above and applied in the notation N5R appears to be inconsistent with the order of the sequence connecting Class B and Class M with which it is compared. The well established sequence, B A F G K M, is usually assumed to represent the order of stellar evolution. Now, if Classes N and R are closely related and are considered to be late types according to Hale, Pickering and other authorities, the larger color index or increasing redness of the stars of Class N, due to the gradual weakening in intensity of rays of shorter wave-length, demands a reversal of the order suggested and the adoption of the order from Class R to Class N and the notation R5N. This is apparent in any classifica-

[11] *Astrophysical Journal,* Vol. 35, p. 132, 1912.

[12] *Publications American Astronomical Society,* Sixteenth Meeting p. 27.

tion that places Class N near the end of the list. In addition to the system mentioned above, Lockyer's classification based upon his meteoritic hypothesis also makes Class N a late type. Russell,[13] however, prefers to assign this class a position near the beginning of the process of stellar development.

OBSERVATIONS

The original program of observations included all known stars of Class R down to the ninth visual magnitude observable in the latitude of Ann Arbor, also a sufficient number of stars of Classes N and O for the purpose of comparison and contrast. The suggestion that the spectrum of stars belonging to Class R resembles the spectrum of the fifth type reversed on a continuous spectrum prompted the inclusion of a number of stars of Class O. It was soon discovered that the resemblance was one of a very general nature, better illustrated by photographs taken with an objective prism spectrograph than with a slit spectrograph; the details brought out by the latter detract from the resemblance, and apparently give no additional clue to a physical relationship between these classes of stars.

All these spectrograms were made with the one-prism spectrograph attached to the 37½-inch Reflector of the Detroit Observatory. Since this spectrograph has been fully described by Professor Curtiss,[14] we will mention only the following features.

Focal length of collimator	686 mm.
Aperture of collimator	36.6 mm.
Refracting angle of prism	64°.5
Focal length of camera	420 mm.
Linear dispersion at λ 4500	47.7 angstroms per mm.

The focal plane of the camera is sensibly flat for the range of spectrum of this investigation λ 4000 to λ5000. The minimum deviation setting is for Hγ rays.

Seed plates were used exclusively, 23's and 27's for stars of Class O, 27's and Graflex for stars of Classes N and R. The coarseness of the silver grains of the Graflex plates and a tendency to form bubbles in the film during the process of development renders them much less satisfactory than the 27's excepting for the faintest stars, where accuracy of measurement was sacrificed for speed during exposure.

A determination of the slit width for the setting 36.0 based upon the measurement of thirty comparison lines on plates 3063A, 3039B, and 3055A, and the ratio of the focal length of the collimator to the focal length of the camera gave the approximate value 0.075 mm.[15] A titanium spark has been used for comparison on all the plates.

The accompanying table of observations, Table II, only partially reveals the arduousness of the observational work. The visual faintness of the stars of Class R and the relatively small amount of blue light combined to render the photography of their spectra difficult under the most favorable conditions, and the success of the work is a testimony to the efficiency of the apparatus used. Frequently an exposure begun under apparently favorable conditions and continued for two or three hours was interrupted before completion by clouds or haze and the exposure time was entirely lost or the spectrogram was so faint that its weight was small for radial velocity and wavelength determination. The work begun at Mount Wilson on stars of Classes N and R with the 60-inch Reflector has been temporarily discontinued, because it was found that the exposures require so much time. Mr. Van Maanen writes, January 23, 1915: "We are waiting for the time when there will be more time available or when we will be able to use a more powerful instrument."

In Table II, C.S.T. refers to Central Standard Time. The seeing (S) and transparency (T) are estimated on a scale 5. The temperature at the beginning (B) and end of exposures (E) are recorded in degrees Centigrade. Slit width (W) for setting 36.0 is approximately 0.075 mm.; the pitch of the screw is one-half millimeter and the head has 100 divisions. The length (L) of the slit is approximately 0.34 mm. for setting 0.8 and 0.46 mm. for setting 1.5, giving a spectrum approximately 0.20 to 0.27 mm. in width respectively.

[13] *Publications American Astronomical Society*, Sixteenth Meeting.

[14] *Publications of the Astronomical Observatory of the University of Michigan*, Vol. 1, p. 37.

[15] Plaskett has found that the exposure time in average seeing is almost inversely proportional to slit-width until this reaches at least 0.075 mm. *Astrophysical Jour.*, Vol. 28, p. 259, 1908. With this slit-width the fainter lines begin to disappear.

TABLE II. JOURNAL OF OBSERVATIONS. CLASS R.

Plate.	Date.	Exposure. C. S. T.	Plate	S.	T.	Dome Temperature. B.	Dome Temperature. E.	Inside Temperature. B.	Inside Temperature. E.	Slit. W.	Slit. L.	Remarks.
DM. − 10° 5057. R.A. $19^h 17^m.6$; Decl. − 10° 54′. Mag. : DM. 7.0, H.P. 7.04.												
2882 A	1914 July 1	9:50 to 12:40	27	2	2.5	17.4	16.0	18.60	18.52	35.0	1.5	Stopped by clouds.
2887 A	July 3	10:00 to 13:20	27	2.5	3	18.3	18.0	20.93	20.70	35.0	1.5	
2914 A	July 15	10:14 to 13:44	27	2	2.5	23.0	22.0	24.80	24.60	35.0	1.5	Fog near end of exposure
2915 A	July 17	9:17 to 12:47	27	1.5	4	21.3	20.0	25.55	25.32	35.5	1.3	
2923 A	July 21	11:32 to 15:02	27	2	3	25.0	21.8	25.75	25.38	36.5	1.0	
2958 A	Aug. 12	10:30 to 13:00	27	2	3	20.1	18.2	20.95	20.84	37.0	1.0	Hazy toward end.
DM. + 20° 5071. R.A. $21^h 59^m.7$; Decl. + 20° 34′. Mag. : DM. 8.7.												
2942 A	1914 Aug. 3	8:50 to 14:20	27	1	3	17.8	14.8	25.25	24.98	36.5	1.0	Trace only.
2966 C	Sept. 4	8:20 to 16:00	27	2	3	16.1	11.6	17.78	17.45	36.0	0.8	
2967 A	Sept. 6	8:15 to 16:15	27	2	3	19.4	13.8	19.80	19.56	36.0	0.8	
2968 A	Sept. 8	7:05 to 16:15	27	2	2.5	12.8	8.0	14.91	14.57	36.0	0.8	Fleecy clouds, 14:00 to 15:00.
DM. + 5° 5223. R.A. $23^h 44^m$; Decl. + 5° 50′. Mag. : DM. 8.7.												
2988 A	1914 Sept. 17	8:45 to 16:15	27	2	2	18.9	15.7	19.69	19.62	36.0	0.8	Clouds, 10:45 to 11:45.
2989 B	Sept. 18	9:20 to 16:20	27	2.5	3	19.7	14.0	20.27	19.95	36.0	0.8	Hazy, 2:00 to 2:30.
DM. + 57° 702. R.A. $3^h 3^m.8$; Decl. + 57° 31′. Mag., DM. 7.9, H.P. 8.06.												
3044 A	1914 Oct. 31	12:05 to 17:25	Graf.	2	2	10.5	8.2	11.12	10.97	36.0	1.0	Light clouds, 1:00 to 3:00.
3079 A	1915 Jan. 2	7.10 to 13:10	Graf.	2	3	−8.6	−12.2	−5.40	−5.54	36.0	0.8	
DM. − 10° 513. R.A. $2^h 30^m$; Decl. − 9° 53′. Mag., DM. 8.0, H.P. 8.26.												
3038 C	1914 Oct. 25	8:50 to 10:30	Graf.	1	1	7.8	....	7.82	.....	36.0	1.0	Incomplete.
3039 B	Oct. 30	8:30 to 13:00	Graf.	2	3	8.1	6.0	10.43	10.33	36.0	1.0	
3055 A	Nov. 11	9:55 to 11:55	27	2	2	2.8	2.2	5.21	5.18	36.0	0.8	Hazy after 11:30.
3063 A	Nov. 23	9:00 to 13:20	27	1.5	3	−3.3	−4.6	−3.23	−3.28	36.0	0.8	Hazy after 1:00

TABLE II. JOURNAL OF OBSERVATIONS. CLASS R. Continued.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME TEMPERATURE. B.	DOME TEMPERATURE. E.	INSIDE TEMPERATURE. B.	INSIDE TEMPERATURE. E.	SLIT. W.	SLIT. L.	REMARKS.
DM. + 61° 667. R.A. $3^h 57^m.2$; Decl. + 61° 31′. Mag., DM. 7.5, H.P. 7.92.												
3051 A	1914 Nov. 6	11:15 to 13:00	Graf.	2	2	3.8	4.2	6.44	6.40	36.0	0.8	Cloudy at 12:30.
3054 C	Nov. 10	12:15 to 14:45	Graf.	1.5	2	4.8	3.1	5.02	5.00	36.0	0.8	Stopped by clouds.
3064 C	Nov. 23	13:45 to 15:00	Graf.	1.5	2	−4.6	−4.2	−3.30	−3.29	36.0	1.0	Stopped by haze.
3073 A	Dec. 21	10.05 to 15.05	Graf.	1.5	3	−12.4	−14.4	−7.66	−7.78	36.0	0.8	Interrupted by clouds.
3088 A	1915 Jan. 23	7:53 to 14:03	27	1	3	−10.6	−16.0	−7.54	−7.61	36.0	1.0	Incomplete.
3089 A	Jan. 26	6:50 to 13:20	Graf.	2	3	−7.0	−9.5	−7.44	−7.55	36.0	1.0	
DM. — 3° 1685. R.A. $6^h 56^m$; Decl. − 3° 7′. Mag., DM. 7.7, H.P. 7.06.												
3087 A	1915 Jan. 20	10:05 to 12:30	Graf.	1	3	−7.2	−10.0	−3.07	−2.60	36.0	1.0	Stopped by clouds.
3094 D	Feb. 8	7:05 to 12:35	27	1.5	4	−6.4	−9.5	−3.42	−3.64	36.0	1.0	
3097 A	Feb. 17	7:00 to 11:30	Graf.	2.4	4	−1.8	−3.8	−0.06	−0.08	36.0	1.0	
DM. + 34° 1929. R.A. $8^h 53^m.6$; Decl. + 34° 9′. Mag., DM. 8.9.												
3138 B	1915 Mar. 11	7:40 to 14:00	Graf.	2	4	0.0	....	1.25	1.10	36.0	0.7	
3143 A	Mar. 16	7:15 to 13:15	Graf.	1.5	4	−1.2	−4.5	2.05	1.87	36.0	0.8	
DM. + 14° 2048. R.A. $9^h 8^m.3$; Decl. + 14° 37′. Mag. DM. 8.8, H.P. 8.68.												
3126 A	1915 Mar. 2	7:35 to 10:35	Graf.	1.5	2.5	−3.0	−7.1	−1.04	−1.12	36.0	0.8	Stopped by clouds.
3127 A	Mar. 3	7:55 to 12:55	Graf.	2	2	−4.6	−6.4	−4.78	−4.72	36.0	0.8	Hazy after 12:00.
3134 A	Mar. 8	7:30 to 12:30	Graf.	2	3	−2.4	−4.4	−2.60	−2.48	36.0	0.8	
DM. + 42° 2811. R.A. $17^h 10^m.4$; Decl. + 42° 15′. Mag., DM. 7.3, H.P. 7.74.												
3128 B	1915 Mar. 3	13:05 to 14:15	Graf.	2	2	−7.0	−7.5	−4.75	−4.75	36.0	0.8	Stopped by clouds.
3135 B	Mar 8	12:45 to 15:45	27	1.5	3	−4.6	−5.7	−2.52	−2.55	36.0	0.8	
3144 B	Mar. 16	13:30 to 17:10	27	2	4	−4.8	−5.7	1.85	1.81	36.0	0.8	
3169 A	Apr. 3	11:50 to 16:50	27	2	3	−1.4	−3.0	1.46	1.40	36.0	0.8	Continued until near dawn.

TABLE II. JOURNAL OF OBSERVATIONS. CLASS N.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME TEMPERATURE. B.	DOME TEMPERATURE. E.	INSIDE TEMPERATURE. B.	INSIDE TEMPERATURE. E.	SLIT. W.	SLIT. L.	REMARKS.

DM. — 5° 4858. V Aquilæ. R.A. $18^h 59^m.1$; Decl. — 5° 50′. Mag. DM. 7.0, H.P. Var.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME B.	DOME E.	INSIDE B.	INSIDE E.	SLIT W.	SLIT L.	REMARKS.
2902 D	1914 July 6	10:33 to 14:33	27	2	3	2.07	1.76	24.22	23.92	35.0	1.5	Trace only.

DM. + 76° 734. R.A. $19^h 25^m.1$; Decl. + 76° 22′.1. Mag., DM. 6.5, H.P. Var.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME B.	DOME E.	INSIDE B.	INSIDE E.	SLIT W.	SLIT L.	REMARKS.
2883 B	1914 July 1	12:59 to 14:40	27	2.5	3	15.8	15.8	18.52	18.50	35.0	1.5	
2921 C	July 20	9:40 to 12:10	27	2	3.5	23.0	22.0	24.11	23.95	35.5	1.5	

19 Piscium. R.A. $23^h 41^m.3$; Decl. + 2° 56′. Mag., DM. 6.2, H.P. Var.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME B.	DOME E.	INSIDE B.	INSIDE E.	SLIT W.	SLIT L.	REMARKS.
2975 B	1914 Sept. 2	10:25 to 13:30	27	1	3	15.4	15.5	22.45	22.39	35.0	1.5	Clouds 25 min.
2977 B	Sept. 11	8:55 to 11:25	27	1.5	3	11.2	10.3	13.21	13.20	35.0	1.5	
2978 D	Sept. 11	11:48 to 14:18	27	2	3	10.1	8.5	10.19	13.01	34.0	1.0	

DM. + 34° 4500. R.A. $21^h 37^m.8$; Decl. + 35° 3′.1. Mag., DM. 6.2, H.P. Var.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME B.	DOME E.	INSIDE B.	INSIDE E.	SLIT W.	SLIT L.	REMARKS.
2916 D	1914 July 17	13:02 to 15:22	27	2	4	20.0	18.5	25.32	25.30	35.5	1.3	
2922 B	July 20	12:28 to 14:48	27	2.5	3	22.0	18.8	23.99	23.85	35.5	1.5	

U Hydræ. R.A. $10^h 32^m.6$; Decl. — 12° 52′. Mag., DM. Var., H.P. Var.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME B.	DOME E.	INSIDE B.	INSIDE E.	SLIT W.	SLIT L.	REMARKS.
3084 A	1915 Jan. 14	12:37 to 15:07	Graf.	1.5	3	−1.5	−2.5	−0.61	−0.63	36.0	1.0	
3086 B	Jan. 15	13:05 to 15:15	Graf.	2	1	−3.5	−3.6	−1.60	−1.61	36.0	1.0	
3090 D	Jan. 26	13:45 to 16:30	Graf.	1.5	3	−9.5	−9.7	−7.60	−7.62	36.0	1.0	
3098 B	Feb. 17	11:45 to 14:00	27	2	4	−3.9	−4.3	−0.09	−0.10	36.0	1.0	
3168 C	Apr. 3	8:15 to 10:45	27	2	4	+0.5	−1.0	1.49	1.47	36.0	0.8	

DM. + 46° 1817. R.A. $12^h 40^m.4$; Decl. + 45° 58′. Mag., DM. Var., H P. Var.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME B.	DOME E.	INSIDE B.	INSIDE E.	SLIT W.	SLIT L.	REMARKS.
3085 B	1915 Jan. 14	15:22 to 17:22	Graf.	2	3	−2.4	−3.6	−0.65	−0.65	36.0	1.0	

TABLE II. JOURNAL OF OBSERVATIONS. CLASS O.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME TEMPERATURE. B.	DOME TEMPERATURE. E.	INSIDE TEMPERATURE. B.	INSIDE TEMPERATURE. E.	SLIT. W.	SLIT. L.	REMARKS.
DM. + 35° 3953. R.A. 20^h 2^m.2; Decl. + 35° 31′. Mag., DM. 7.0, H.P. 7.01.												
2938 A	1914 July 29	12:00 to 2:15	27	1.5	4	15.5	14.6	19.05	18.76	35.5	1.0	
2950 A	Aug. 5	11:40 to 12:40	27	2	3	20.6	19.0	22.96	22.85	35.5	1.0	
DM. + 43° 3571. R.A. 20^h 17^m.1; Decl. + 43° 32′. Mag., DM. 7.5, H.P. 6.83.												
2982 D	1914 Sept. 14	12:43 to 14:38	27	1	3	16.8	16.2	17.57	17.53			Cloudy near end.
3012 B	Oct. 1	11:08 to 12:58	27	3	3.5	11.0	10.0	13.37	13.32	34.0	1.8	
DM. + 37° 3821. R.A. 20^h 8^m.5; Decl. + 38° 3′. Mag., DM. 7.1, H.P. 7.44.												
2981 A	1914 Sept. 13	11:35 to 13:35	27	2	2	14.1	13.8	15.10	15.09	34.0	1.0	Interrupted by clouds.
2990 A	Sept. 19	12:15 to 14:00	27	2.5	3	19.2	19.2	21.06	21.07	34.0	1.5	Spoiled in developing.
3011 A	Oct. 1	9:03 to 10:53	27	3	4	12.8	11.1	13.40	13.37	34.0	1.8	
λ Cephei. R.A. 22^h 8^m.1; Decl. + 58° 56′. Mag., DM. 5.6, H.P. 5.19.												
2933 A	1914 July 27	12:27 to 12:57	27	2	3	19.6	19.1	25.67	25.58	34.5	2.0	
2934 B	July 27	13:03 to 14:23	23	2	3	19.1	19.0	25.58	25.55	34.5	2.0	
2952 C	Aug. 5	14:08 to 14:23	23	2	3	18.9	18.9	21.84	21.84	34.5	2.0	
2953 B	Aug. 5	14.55 to 15:20	23	2	2	18.9	18.9	21.83	21.83	34.5	2.0	
2979 A	Sept. 11	14:40 to 15:40	23	2	3	8.5	8.0	12.90	12.92	34.0	1.0	
2983 B	Sept. 14	14:57 to 15:27	23	1.5	2.5	16.2	16.1	17.53	17.50	34.0	1.5	
2984 C	Sept. 14	15:37 to 16:07	23	1.5	2.5	16.0	15.8	17.50	17.48	33.0	2.0	

THE SPECTROGRAMS

The spectra of stars of Class R are marked by strong absorption bands, numerous dark lines, and a few bright lines. Only plates of the stars + 42° 2811 and — 10° 5057 gave a spectrum above λ 4188 strong enough for the measurement of lines; sufficient continuous spectrum is visible, however, beyond this limit on plates of other stars to indicate the presence of violet rays. The H and K lines are clearly seen on plates of + 42° 2811. Some plates show a sharp drop in intensity at λ 4216, others fade away gradually. The calcium line λ 4227 is strong. The broad G group, extending in some cases from λ 4295 to λ 4315, is the most prominent feature of this region, showing almost complete absorption on some of the plates. The line λ 4384 is conspicuous. Hγ is present, but is not prominent. On plates of the stars showing the strongest ordinary bands, there is also strong absorption from λ 4395 toward the violet rendering the spectrum very weak as far as Hγ or even as far as G in some cases. The

most prominent feature of the whole spectrum under consideration, from the violet end to λ 5000, are the strong absorption bands with head at λ 4737 when the bands are weaker and at λ 4752 when they are stronger. These bands are sharply defined toward the red but gradually fade away toward the violet, usually to about λ 4630-40. The continuous spectrum on the red side of these bands is much stronger than it is on the other side, the relative intensity differing greatly in the different stars; in general, the spectrum showing the stronger absorption bands suffers the greater loss in intensity on the violet side. An absorption line varying in intensity in the different stars occupies the position of $H\beta$, but a companion line and the low dispersion in this region renders its identification difficult. On some plates it is very weak, on others not discernible. $H\beta$ does not clearly appear as a bright line on any plate. The intensity of the spectrum, which is a maximum in the broad bright zone adjoining the head of the strong absorption band, gradually grows less toward the red limit of visibility of the photographic plate; at λ 5000 the spectrum is much fainter for Class R stars as a rule than for Class N stars taken under the same conditions. Prominent lines varying in intensity from star to star are found at λλ 4876, 4886, 4921, 4958, and 4985.

The features here mentioned will be discussed in the section on qualitative results.

MEASUREMENT AND REDUCTION

Measurement. The spectrograms were measured on Measuring Engines No. 1 and No. 3 of this Observatory. The pitch of the screws is one-half millimeter and the least reading 0.0005 mm. Determinations of the periodic error for different sections indicate that no corrections to the micrometer readings are necessary. Low magnifying power gave the best results on account of the coarseness of the silver grains of the photograph plates used; for the Graflex plates power 7 to 8 was used, for 27's power 12 to 15. All the available star lines were measured for wave-length determination. About 25 comparison lines were measured on each plate. The average of three settings on a star line was taken. The mean of two readings on the inner tip of the upper comparison line was averaged with the mean of two readings on the inner tip of the lower. This has a double advantage: in the first place, if the point is fairly symmetrical its bisection gives a better result than the bisection of a broad line; and in the second place, the effect due to the curvature of the slit image on the plate is minimized. In our work the curvature correction was not appreciable. All the plates were measured direct and reversed to eliminate personal equation as far as possible.

Radial Velocity Determination. The method of reduction proposed by Professor Curtiss[16] has been followed using the moon as the standard velocity source. For the standard table about forty lines were selected, that were found to be more or less common to stars of Class R and the solar spectrum, and about 25 comparison lines of average intensity well distributed throughout the region λ 3900 to λ 5100.

The first standard table was made from three moon plates with titanium comparison. During the course of the observations the spectrograph was readjusted, which resulted in a change of dispersion sufficient to necessitate a corresponding change in the standard table. Accordingly, the second standard table was prepared by changing the dispersion of the old table to the new by means of a graphical method, plotting the micrometer readings as abscissae and the differences in readings between the old and the new as ordinates. A smooth curve was then formed which together with the scale correction gave the means of conversion. The micrometer readings of the comparison lines in the second standard table are based upon a larger number of measurements than in the first standard table; also a few comparison lines were rejected and others substituted, and a few additional moon lines were included, which were found to be common to Class R stars.

The method of making the lines homogeneous was applied in the case of star — 10° 5057, for which five plates were available. The maximum correction to the computed velocity for a single plate due to this somewhat laborious process was 0.38 km. for plate 2887 A. The small number of plates available for each star and the degree of precision required did not warrant the general adoption of this refinement.

[16] *Astrophysical Jour.*, Vol. 20, p. 149, 1904.

Wave-length Determination. Wave-lengths were determined by means of the Hartmann interpolation formula,

$$\lambda = \lambda_0 + \frac{c}{R_0 - R}.$$

In the determination of the constants of the formula the titanium lines λ 4078.632, λ 4338.081, and λ 4981.916, expressed in Rowland's scale, were used as standard lines in the first standard table. These lines are among the ones selected by Mr. Mellor as standards for "A Study of the Titanium Spark as a Comparison Spectrum in the Single-Prism Spectrograph." The line λ 4163.829 of his list was substituted for λ 4078.632 in the second standard table.

The constants for the first standard table are

$$R_0 = 185.108,$$
$$\lambda_0 = 2,204.293,$$
$$c = 224,289.5.$$

For the second standard table the constants are

$$R_0 = 186.184,$$
$$\lambda_0 = 2,197.682,$$
$$c = 227,282.66.$$

The residuals, observed wave-length minus computed wave-length, which form the ordinates of the correction curves, are based upon the list of titanium lines given by Mr. Mellor, in these *Publications*, Vol. 1, p. 140. The correction curve to accompany the use of the first set of constants is not well determined; but it is more symmetrical than the second, due to the use of standard lines separated by intervals more nearly equal.

Before application of the formulæ

$$\lambda = 2,204.293 + \frac{224,289.5}{185.108 - R}, \qquad (1)$$

and

$$\lambda = 2,197.682 + \frac{227,282.66}{186.184 - R}, \qquad (2)$$

the micrometer reading, R was corrected for plate velocity. This correction was obtained by multiplying the plate velocity by $\frac{dR}{dv}$, and is applied with the sign changed, since a positive velocity indicates a displacement toward the red or larger wave-length and the micrometer readings increase in the same direction. After R was corrected for all the plates of a single star the mean value for each line was found, due consideration being given to the quality of the line on the individual plates. This value of R was substituted in the Hartmann formula, the application of which was greatly facilitated by the use of the Millionaire computing machine. The resulting value of the wave-length was corrected by means of the ordinate of the correction curve corresponding to the micrometer reading of the line, which gave the final value of the wave-length. After the wave-lengths of stars $-10°$ 5057 and $+57°$ 702 had been determined by this method they were used as standards and the difference in R for the other stars was changed into difference in λ by the factor $\frac{d\lambda}{dR}$, tabulated in the standard table. The application of this difference to the computed wave-length in the standard star gave the value of λ directly, saving much time in computation. These values of the wave-lengths are tabulated for each star in the *Table of Mean Wave-Lengths.*

Degree of Precision. The visual faintness of the stars of Class R and their greater photographic faintness required the use of fast plates, the coarse silver grains of which necessitated a low magnifying power and interfered with precise measurement. The wideness of the slit, usually 0.075 mm., combined with the relatively low dispersion, tended to produce broad lines and blends instead of sharp well-defined slit images. The change in intensity of the lines passing from the moon plates to those of Class R and Class N stars introduce displacements of unknown magnitude. While the shift of ordinary lines with spectral type may not be large between the solar spectrum and spectra of Class R stars, there appears to be a marked change in the position of the center of many measured lines, probably due to the presence of new components or to the unequal change in the relative intensity of the components passing from the solar type to types VI and IV. A few cases that will be pointed out later seem to indicate a systematic shift from star to star passing along the sequence of stars arranged in the order of the intensity of the absorption band. The presence of bright lines also tends to

shift the center of mass of adjacent absorption lines. Error due to this cause was avoided in radial velocity determination by omitting as far as practicable the use of disturbed lines.

The precision of radial velocity determinations is indicated by the tabulated probable errors accompanying the plate velocities, which are based upon the agreement of the velocities given by the lines of the plate. The average for a plate velocity is $\pm$ 2.06 km. for the ten Class R stars. The small number of lines on some plates available for comparison with the lines of the standard table accounts for the large average probable error in such cases. The average number of lines used for each plate was 17, giving an average probable error for a single line of 7.18 km., or in wave-lengths

At λ 4000, $\pm$ 0.11 Å,
At λ 4500, $\pm$ 0.12 Å,
At λ 5000, $\pm$ 0.14 Å.

On this basis the probable error of the mean wave-length of a line measured on ten plates is about $\pm$ 0.04 Å, and for a line measured on five plates the probable error is about $\pm$ 0.06 Å.

After the lines were made homogeneous in the case of star $-10°$ 5057, for which five plates were available, the average probable error of the wave-length of a single line was found to be $\pm$ 0.050 Å.

MEAN WAVE-LENGTHS

In the table of mean wave-lengths the stars at the head of the columns are arranged in the order of the intensity of the absorption band with head at λ 4737. Under each star are three columns giving respectively the quality, intensity, and computed wave-length of the line. G, F, and P stand for good, fair, and poor, respectively. Occasionally a line is designated as wide (W), very wide (VW), sharp (S), diffuse (Dif.), or nebulous (N or Neb.). Max. stands for the position of maximum intensity in a broad line or band, Str. for the strongest of a group of lines, and Bl. for blend. Br. indicates an emission line. The intensity is estimated on a scale of 10; special difficulties, however, render these estimates approximations only. The last column but one of the table gives the mean wave-lengths of lines common to two or more stars. In general a single star line occupies a single horizontal line of the table, but owing to uncertainties of identification this may not always be the case. The lines of the table are numbered consecutively for convenience of reference.

TABLE III. MEAN WAVE-LENGTHS. CLASS R.

No.	+ 42° 2811.	− 10° 5057.	+ 5° 5223.	+ 20° 5071.	+ 34° 1929.	− 10° 513.
	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.
1	W 5 4188.68	F 5 4187.77	P 3 4187.75	.. ..	.. ..	.. ..
2	.. ..	F 2 4191.44	.. ..	F 2 4191.96	.. ..	.. ..
3	P 1 4195.07	W 2 4195.71	P 2 4195.68	.. ..	.. ..	F 2 4196.16
4	F 2 4196.57	G 3 4196.72	.. ..	.. ..	.. ..	.. ..
5	.. ..	F 3 4201.83	.. ..	.. ..	.. ..	.. ..
6	.. ..	.. ..	.. ..	F 3 4203.00	.. ..	.. ..
7	W 5 4207.96	W 3 4205.27	F 4 4208.69	F 1 4206.46	.. ..	P 2 4207.29
8*	G 10 4215.67	G 10 4215.46	.. ..	.. ..	.. ..	F 7 4215.64
9	Head 4216.59	Head 4216.23	.. ..	.. ..	.. ..	.. ..
10	F 3 4218.90	.. ..	.. ..	P 3 4218.93	.. ..	P 3 4218.40
11	.. ..	F 3 4220.29	.. ..	.. ..	P 3 4220.63	.. ..
12	P 2 4223.19	F 2 4223.16	.. ..	P 2 4223.00	.. ..	F 3 4223.28
13	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
14	.. ..	.. ..	.. ..	F 2 4225.89	.. ..	.. ..
15*	G 10 4227.12	G 7 4227.32	F 8 4227.11	F 7 4227.22	F 7 4227.12	F 7 4227.02
16	Edge 4227.94	.. ..	.. ..	.. ..	.. ..	.. ..
17	F 2 4230.19	F 1 4230.50	.. ..	.. ..	.. ..	F 2 4229.85
18*	F 4 4233.51	G 6 4233.30	.. ..	W 4 4232.92	F 3 4233.91	F 3 4233.34
19*	F 5 4236.51	F 3 4236.31	.. ..	.. ..	W 4 4236.68	P 3 4236.63
20	.. ..	F 4 4239.14	.. ..	G 5 4238.58	.. ..	.. ..
21	Edge 4240.56	.. ..	.. ..	.. ..	.. ..	.. ..
22	.. ..	F 2 4242.60	.. ..	.. ..	.. ..	.. ..
23*	F 5 4243.32	.. ..	F 3 4243.11	.. ..	W 8 4242.99	Bl. 5 4243.47
24	.. ..	.. ..	.. ..	W 5 4244.68	.. ..	.. ..
25	.. ..	G 5 4247.24	.. ..	.. ..	.. ..	.. ..
26	4248.02	.. ..	4248.01	.. ..	4247.87	4247.86
27*	F 3 4250.44	F 3 4250.46	F 3 4250.76	F 5 4250.49	W 4 4250.86	4250.86
28	.. ..	F 2 4252.65	.. ..	.. ..	.. ..	.. ..
29	.. ..	.. ..	W 3 4254.62	F 3 4254.43	.. ..	P 3 4254.56
30	F 4 4255.72	.. ..	.. ..	.. ..	F 2 4255.29	.. ..
31	.. ..	P 2 4256.48	.. ..	.. ..	.. ..	.. ..
32	.. ..	.. ..	F 3 4257.61	P 2 4257.13	.. ..	.. ..
33	4258.04	F 2 4258.47	F 2 4258.70	.. ..	.. ..	F 3 4259.09
34*	Center 4260.63	F 4 4260.74	.. ..	F 3 4260.20	P 5 4260.70	.. ..
35	.. ..	.. ..	F 4 4261.42	Br. 2 4261.46	.. ..	.. ..
36	4262.29	.. ..	.. ..	.. ..	.. ..	.. ..
37	.. ..	.. ..	.. ..	F 2 4263.03	.. ..	.. ..
38	F 3 4264.83	.. ..	.. ..	.. ..	F 2 4264.38	F 3 4264.64
39	.. ..	.. ..	.. ..	W 5 4266.83	.. ..	.. ..
40	F 3 4268.28	W 4 4269.12	F 4 4268.29	.. ..	4267.88	F 4 4267.67
41	.. ..	.. ..	.. ..	P 2 4270.44	.. ..	.. ..
42*	F 5 4271.98	G 4 4271.96	F 3 4271.67	.. ..	F 4 4272.02	F 4 4271.79
43	.. ..	.. ..	.. ..	.. ..	.. ..	F 2 4274.65
44	F 3 4275.21	F 4 4275.26	F 4 4275.01	G 4 4275.86	F 4 4275.48	.. ..
45	F 1 4277.09	F 2 4278.07	.. ..	.. ..	.. ..	.. ..

TABLE III. MEAN WAVE-LENGTHS. CLASS R.

No.	+ 61° 667.			+ 3° 1685.			+ 57° 702.			+ 14° 2058.			Mean and Identification.	
	Character, intensity, and wave-length.			Character, intensity, and wave-length.			Character, intensity, and wave-length.			Character, intensity, and wave-length.			Angstroms.	Element.
1	..	..	....	..	..	....	..	..	....	..	..	....	4187.8	Fe.
2	..	..	....	..	..	....	..	..	....	..	..	....	4191.7	Fe.
3	..	..	....	..	..	....	..	..	....	..	..	....	4195.8	Fe.
4	..	..	....	..	..	....	..	..	....	..	..	....	4196.7	Cy.
5	..	..	....	..	..	....	..	..	....	..	..	....	4201.8	Fe.
6	..	..	....	..	..	....	F	4	4203.01	..	..	....	4203.0	
7	..	..	....	..	..	....	..	..	....	..	..	....	......	
8*	..	..	....	F	5	4215.43	F	8	4215.69	F	7	4215.81	4215.6	Cy. Fe.?
9	..	..	....	..	..	....	Head		4216.16	Head		4216.43	4216.4	
10	..	..	....	..	..	....	..	..	....	..	..	....	4218.8	Zr.
11	..	..	....	P	3	4220.06	..	..	....	Br. ?	2	4220.38	4220.3	Fe.
12	..	..	....	..	..	....	..	..	....	P	2	4223.01	4223.2	
13	..	..	....	Bl.	5	4224.21	..	..	....	..	..	....	......	
14	..	..	....	..	..	....	..	..	....	..	..	....	......	
15*	..	..	....	N	5	4227.35	N	7	4227.01	W	10	4227.29	4227.2	Ca. Fe.
16	..	..	....	..	..	....	..	..	....	Edge		4228.11	4228.0	
17	..	..	....	F	2	4229.99	..	..	....	F	1	4230.45	4230.2	Fe.
18	..	..	....	F	3	4233.71	F	3	4233.36	F	3	4233.89	4233.5	Fe.
19	..	..	....	P	3	4236.62	F	4	4237.08	F	4	4237.08	4236.7	
20	..	..	....	..	..	....	..	..	....	..	..	....	......	
21	..	..	....	..	..	....	..	..	....	..	..	....	......	
22	..	..	....	..	..	....	..	..	....	..	..	....	......	
23*	P	3	4243.32	G	4	4243.27	F	4	4243.31	G	5	4243.56	4243.3	Fe.
24	..	..	....	..	..	....	..	..	....	..	..	....	......	
25	..	..	....	..	..	....	..	..	....	..	..	....	......	
26	..	..	....	..	..	....			4247.48			4248.01	......	
27*	..	..	....	W	3	4250.66			4250.62	W	5	4250.66	4250.6	Fe. blend.
28	..	..	....	..	..	....	..	..	....	Br. ?	1	4252.78	......	
29	P	3	4254.62	W	8	4254.95	P	5	4254.90	..	..	....	4254.7	Cr.
30	..	..	....	N	4	4255.70	..	..	....	G	10	4255.46	4255.5	Fe. Cr.
31	..	..	....			4256.56	..	..	....	..	..	....	......	
32	..	..	....	..	..	....	..	..	....	Br. ?	2	4257.82	......	
33	..	..	....	..	..	....	..	..	....			4258.61	4258.8	Fe.
34	P	4	4260.37	W	6	4260.72	P	3	4260.57	..	..	....	4260.6	
35	..	..	....			4261.34	..	..	....	Str.		4261.07	......	
36	..	..	....	..	..	....	..	..	....			4262.44	......	Fe.
37	..	..	....	..	..	....	..	..	....	..	..	....	......	
38	..	..	....	..	..	....	..	..	....	F	2	4265.13	4264.7	Fe.
39	..	..	....	..	..	....	..	..	....	..	..	....	......	
40	F	3	4267.90	F	3	4268.28	..	..	....			4268.66	4268.0 ?	Fe. C.
41	..	..	....	..	..	....	..	..	....	..	..	....	......	
42*	F	3	4271.49	F	3	4271.85	F	4	4271.85	F	3	4272.24	4271.9	Fe.
43	..	..	....	..	..	....	..	..	....	..	..	....	......	
44	P	3	4275.14	F	4	4275.16	..	..	....	F	4	4275.33	4275.3	Cr.
45	..	..	....	..	..	....	..	..	....	F	1	4278.28	4278.1	

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811.			— 10° 5057.			+ 5° 5223.			+ 20° 5071.			+ 34° 1929.			— 10° 513.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
46*	G	6	4280.56	F	3	4280.74	G	4	4280.55	..	..	....	Bl.	5	4280.58	G	5	4280.42
47	..	..	....	..	..	....	..	..	....	G	6	4281.38	..	..	....	..	..	....
48	F	1	4283.06	F	2	4282.91	..	..	....	..	..	....	..	..	....	..	..	....
49	F	4	4286.09	F	2	4286.18	F	3	4286.02	F	5	4286.62	N	3	4286.00	F	4	4285.90
50*	F	3	4289.88	F	6	4290.11	F	3	4289.83			4290.01	F	4	4290.11	F	3	4289.67
51	F	3	4291.74	..	..	....	P	2	4291.97	..	..	....	..	..	....	..	..	....
52	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
53	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
54	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	F	2	4294.44
55	S	2	4294.94	F	3	4295.31	F	3	4295.22	..	..	....	..	..	....	..	..	....
56*	F	5	4300.08	G	8	4299.98	F	5	4300.02	..	..	....	..	..	....	..	..	....
57	P	1	4303.04	F	2	4302.03	..	..	....	..	..	....	..	..	....	W	4	4303.52
58	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
59	..	..	....	F	3	4305.73	..	..	....	..	..	....	..	..	....	..	..	....
60	..	..	....	..	..	....	..	..	....	..	..	....	F	5	4306.62	..	..	....
61	P	2	4308.41	W	5	4308.72	W	4	4308.50	..	..	....	..	..	....	..	..	....
62	..	..	....	..	..	....	..	..	....			4310.08	..	..	....	..	..	....
63*	F	4	4314.17	G	6	4314.69			4314.62	..	..	....	F	6	4314.77	F	2	4314.63
64	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	F	2	4317.57
65	..	..	....	..	..	....	..	..	....	..	..	....			4318.55	..	..	....
66	F	1	4319.24	..	..	....	..	..	....	W	6	4319.39	..	..	....	..	..	....
67	..	..	....	..	..	....	F	2	4320.16	..	..	....	..	..	4320.68	..	..	....
68	F	1	4321.31	F	4	4321.20	..	..	....	..	..	....	..	..	....			4321.93
69	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
70			4324.16	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
71*	G Max.		4325.62	G	7	4325.59	G	10	4324.62	F	3	4324.79	W	6	4325.42	W	8	4324.68
72			4327.29	..	..	....	..	..	....	..	..	....	..	..	....			4326.65
73	..	..	....	..	..	....	..	..	....	F	3	4329.05	..	..	....	..	..	....
74	F	2	4330.92	F	4	4330.77	F	3	4330.63	..	..	....	..	..	....	F	3	4330.01
75	F	2	4334.42	F	3	4334.12	F	4	4333.93	F	5	4333.33	P	2	4334.21	F	2	4333.44
76*	F	4	4337.91			4337.72	G	6	4337.88	..	..	....	F	4	4337.89	F	3	4337.51
77	..	..	....	F	2	4339.99	..	..	....	F	2	4339.02	..	..	....	..	..	....
78*	F	6	4340.42	..	..	....	F	3	4340.90	..	..	....	F	3	4340.54			4340.34
79	..	..	....	..	..	....	..	..	....	F	3	4342.91	..	..	....	..	..	....
80	F	3	4344.26	F	4	4344.40	F	3	4343.97	..	..	....	F	2	4343.88	P	3	4344.04
81*	F	4	4347.69	F	3	4347.60	F	3	4347.58	G	5	4347.43	F	3	4347.61	G	6	4347.79
82	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
83	..	..	....	..	..	....	..	..	....	F	3	4351.22	..	..	....	..	..	....
84*	G	7	4352.11	W	5	4351.67	G	6	4352.01	..	..	....	F	7	4351.04	F	5	4352.32
85	..	..	....	..	..	....	..	..	....	F	2	4354.71	..	..	....	..	..	....
86	F	3	4355.87	F	3	4355.17	F	2	4355.56	..	..	....	F	4	4355.61	..	..	....
87	..	..	....	..	..	....	..	..	....	F	2	4358.08	..	..	....	..	..	....
88	F	4	4359.78	P	5	4359.41	F	3	4359.76	..	..	....	F	3	4359.70	..	..	....
89	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
90	..	..	....	..	..	....	..	..	....	F	3	4362.93	..	..	....	..	..	....

TABLE III MEAN WAVE LENGTHS. CLASS R—Continued.

No.	+61 667. Character, Intensity, and Wave-length	−3 1685. Character, Intensity, and Wave-length.	+57 702. Character, Intensity, and Wave-length.	+14 2038. Character, Intensity, and Wave-length.	Mean and Identification. Angstroms.	Element.
46*	F 3 4280.63	P 3 4280.60	P 4 4280.02	F 4 4280.81	4280.6	Cr.
47	.. ..	.. ..	.. ..	.. ..	......	
48	.. ..	.. ..	.. ..	F 3 4283.08	4283.0	Ti. Ca.
49	.. ..	F 3 4286.31	.. ..	F 4 4286.65	4286.2	Ti.
50*	.. ..	P 3 4290.02	F 3 4289.90	Bl. 4 4289.98	4289.9	Cr. Ca.
51	.. ..	F 3 4291.85	.. ..	F 3 4291.85	4291.8	Fe. Cr.
52	.. ..	.. ..	F 1 4292.43	.. ..	......	
53	.. ..	.. ..	.. ..	4293.95	.....	
54	.. ..	.. ..	.. ..	.. ..	......	
55	.. ..	.. ..	F 1 4295.03	.. ..	......	
56*	.. ..	F 2 4300.02	.. ..	F 4 4300.13	4300.0	G. Fe. Ti.
57	.. ..	.. ..	.. ..	.. ..	......	
58	.. ..	.. ..	F 3 4304.91	.. ..	......	
59	.. ..	F 3 4305.86	.. ..	.. ..	......	
60	.. ..	.. ..	.. ..	.. ..	......	
61	.. ..	.. ..	.. ..	.. ..	......	
62	.. ..	.. ..	.. ..	.. ..	......	
63*	G 3 4314.82	F 3 4314.17	Edge 4315.50	Edge 4315.09	4314.7	Ti. ?
64	.. ..	.. ..	.. ..	.. ..	......	
65	.. ..	.. ..	.. ..	.. ..	......	
66	.. ..	.. ..	.. ..	.. ..	......	
67	.. ..	.. ..	.. ..	.. ..	......	
68	. .. .	.. ..	.. ..	F 2 4321.67	4321.5	
69	4323.55	.. ..	.. ..	.. ..	......	
70	.. ..	.. ..	P 3 4324.18	F 3 4324.12	......	Ti. Cr.
71*	.. ..	.. ..	F 3 4326.00	.. ..	......	Fe.
72	4326.38	.. ..	4327.37	.. ..	......	
73	.. ..	. .. .	F 3 4329.59	.. ..	......	
74	F 2 4329.89	F 3 4330.37	.. ..	F 4 4330.13	4330.1	V.
75	P 3 4333.89	W 5 4334.73	.. ..	F 3 4334.65	4334.1	
76*	F 3 4337.81	4337.63	P 3 4337.73	.. ..	4337.8	Cr.
77	.. ..	.. ..	.. ..	.. ..	......	
78	P 2 4340.92	4340.50	P 2 4340.16	P 2 4341.05	4340.5	Hγ.
79	.. ..	.. ..	F 1 4342.85	.. ..	4342.9	
80	.. ..	.. ..	.. ..	F 3 4343.92	4344.1	Cr. Blend.
81*	W 4 4347.58	.. ..	F 3 4347.77	.. ..	4347.6	
82	.. ..	.. ..	.. ..	F 2 4348.26	......	
83	.. ..	.. ..	.. ..	.. ..	......	
84	F 6 4352.08	.. ..	F 4 4352.28	.. ..	4352.0	Cr. Mg.
85	.. ..	.. ..	.. ..	.. ..	......	
86	F 4 4355.26	.. ..	.. ..	.. ..	4355.5	Ca.
87	.. ..	.. ..	.. ..	.. ..	......	
88	.. ..	.. ..	F 3 4359.62	.. ..	4359.7	Cr.
89	P 2 4360.49	.. ..	.. ..	.. ..	......	
90	.. ..	.. ...	.. ..	.. ..	......	

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811.			— 10° 5057.			+ 5° 5223.			+ 20° 5071.			+ 34° 1929.			— 10° 513.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH		
91	W	4	4363.88	W	Max.	4363.67	F	4	4363.83	..	..	....	F	3	4363.49	F	4	4363.31
92			4366.61	..	..	....	P	2	4366.86	P	3	4366.98	..	..	....	..	..	....
93*	P	3	4367.41	P	3	4367.70	..	..	....	..	..	....	F	3	4367.90	F	3	4367.17
94	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
95	P	1	4370.39	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
96	..	..	....	F	4	4371.37	..	..	....	..	..	....	..	..	....	F	4	4371.41
97	..	..	....	..	..	....	P	2	4373.25	..	..	....	..	..	....	..	..	....
98	W	5	4374.76	F	6	4374.86	..	..	....	..	..	....	..	..	....	..	..	....
99	..	..	....	..	..	....	F	3	4375.93	..	..	....	F	4	4375.54	F	4	4376.13
100	P	2	4380.33	P	2	4380.09	..	..	....	..	..	....	..	..	....	..	..	....
101			4382.95	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
102	G	10	4384.06	..	..	....	VW	8	4383.84	..	..	....	G	9	4384.00	F	4	4383.96
103			4385.69			4385.28	..	..	....	..	..	....	..	..	....	..	..	....
104	..	..	....	..	..	....	..	..	....	W	3	4386.20	..	..	....	..	..	....
105	..	..	....	F	1	4388.02	F	3	4388.74	..	..	....	F	2	4388.43	..	..	....
106	W	4	4389.97	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
107	..	..	....	F	4	4390.99	F	3	4390.82	..	..	....	..	..	....	F	3	4390.26
108	..	..	....	..	..	....	..	..	....	..	..	....			4392.25	..	..	....
109*	F	4	4395.24	G	5	4395.22	G	3	4395.12	F	3	4395.03	F	3	4395.46	G	6	4395.04
110	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
111	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
112*	F	5	4400.82	G	8	4400.52	F	4	4400.47	F	3	4400.69	F	4	4400.77	F	5	4400.37
113	Br.	2	4403.19	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
114*	G	5	4404.89	F	4	4404.67	G	7	4404.87	F	2	4404.79	G	6	4404.84	G	4	4404.78
115	F	4	4408.96	G	7	4408.83	G	6	4408.63	..	..	....	F	3	4408.98	F	3	4408.63
116	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
117	..	..	....	P	2	4411.89	..	..	....	..	..	....	..	..	....	..	..	....
118	Br.	2	4413.04	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
119	..	..	....	..	..	....	..	..	....	Br.	2	4414.24	..	..	....	..	..	....
120*	F	6	4415.41	F	4	4415.09	G	6	4415.27	..	..	....	G	6	4415.56	F	5	4414.97
121	..	..	....	..	..	....	..	..	....	F	3	4416.76	..	..	....	..	..	....
122	Edge		4418.22	F	5	4417.94	..	..	....	..	..	....	..	..	....	..	..	....
123	..	..	....	..	..	....	..	..	....	F	1	4420.17	..	..	....	..	..	....
124	F	4	4422.92	F	3	4422.88	F	4	4422.52	..	..	....	W	4	4422.47	F	3	4422.39
125	..	..	....	..	..	....	..	..	....	W	4	4425.46	N	3	4426.29	..	..	....
126*	F	3	4430.63	F	4	4430.25	G	4	4430.50	F	5	4430.78	P	3	4430.59	F	4	4430.76
127*	W	8	4435.23	F	6	4435.08	W	4	4435.27	W	1		W	4	4435.25	G	4	4435.28
128	..	..	....	..	..	....	..	..	....	P	4	4437.15	F	1	4437.49	..	..	....
129	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
130	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
131	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	F	4	4442.00
132*	W	10	4442.99	G	10	4443.37	G	8	4442.66	F	2	4442.80	W	8	4442.97	..	..	....
133	..	..	....	..	..	....	..	..	....	F	3	4445.16			4444.77	..	..	....
134	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
135	F	1	4447.46	F	2	4447.37	F	3	4446.02	..	..	....	..	..	....	..	..	....

TABLE III. MEAN WAVE-LENGTHS. CLASS R—Continued.

NO.	+ 61 667.	− 3 1685.	+ 57 702.	+ 14° 2048.	MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	ANGSTROMS.	ELEMENT.
91	F 3 4363.53	.. ..	.. ..	.. ..	4363.6	
92	.. ..	.. ..	.. ..	.. ..	4366.9	
93*	G 1 4367.12	.. ..	.. ..	.. ..	4367.6	Fe.
94	W 2 4369.05	.. ..	.. ..	.. ..	......	
95	.. ..	.. ..	.. ..	.. ..	......	
96	.. ..	.. ..	.. ..	.. ..	4371.4	Cy. Cr.
97	.. ..	.. ..	.. ..	.. ..	......	
98	.. ..	.. ..	.. ..	.. ..	4374.8	
99	W 4 4375.36	.. ..	F 3 4375.38	.. ..	4375.7	Cr. Fe.
100	.. ..	.. ..	.. ..	.. ..	......	
101	.. ..	.. ..	.. ..	.. ..	......	
102	W 6 4383.98	F 3 4383.85	P 3 4384.08	F 3 4384.30	4384.1	Fe.
103	.. ..	.. ..	.. ..	.. ..	......	
104	.. ..	.. ..	.. ..	.. ..	......	
105	.. ..	.. ..	.. ..	.. ..	......	
106	.. ..	.. ..	.. ..	P 4 4389.59	......	
107	F 3 4391.02	.. ..	.. ..	F 3 4391.15	4390.8	V. ?
108	.. ..	F 1 4392.40	.. ..	.. ..	......	
109*	G 9 4395.01	F 7 4395.07	W 6 4394.67	G 9 4394.73	4395.1	V.
110	Edge 4395.63	Edge 4396.01	Edge 4395.78	F 4 4395.61	4395.7	Ti.
111	.. ..	.. ..	.. ..	Edge 4395.97	......	
112*	F 6 4400.24	F 5 4400.71	F 4 4400.71	G 6 4400.71	4400.6	
113	.. ..	Br. 1 4402.57	.. ..	Br. 2 4403.21	4403.0	
114*	G 9 4404.95	G Max. 4404.78	G 8 4405.06	[F 7 4405.47]	4404.8	Fe.
115	F 6 4408.66	.. ..	F 6 4408.70	F 6 4408.85	4408.8	V. ?
116	.. ..	Edge 4409.58	Edge 4409.00	Edge 4409.47	4409.4	
117	.. ..	.. ..	.. ..	.. ..	......	
118	Rev. 1 4412.15	Rev. 1 4412.86	.. ..	F 2 4412.72	......	Cr. O in sun.
119	.. ..	.. ..	.. ..	.. ..	......	
120*	G 8 4415.28	G 5 4415.52	F 6 4415.43	G 5 4415.82	4415.4	Fe.
121	.. ..	.. ..	.. ..	.. ..	......	
122	.. ..	G 6 4418.04	.. ..	.. ..	4418.1	Fe. Ti.
123	.. ..	.. ..	.. ..	.. ..	......	
124	F 4 4422.40	W 4 4422.60	.. ..	F 3 4422.71	4422.6	Fe.
125	.. ..	F 1 4426.76	.. ..	P 2 4426.10	4426.2	V.
126*	F 3 4430.35	F 4 4430.70	F 3 4430.72	[F 4 4431.13]	4430.6	Fe.
127*	G 10 4435.68	W Max. 4435.43	G 8 4435.47	G 8 4435.82	4435.4	Ca.
128	.. ..	.. ..	.. ..	.. ..	4437.4	
129	Rev. 1 4438.30	.. ..	.. ..	.. ..	......	
130	.. ..	Br. 2 4439.65	Br. 1 4439.12	Br. 2 4439.21	4439.3	
131	.. ..	.. ..	.. ..	.. ..	......	
132*	G 10 4442.77	F 8 4442.80	F 5 4442.79	G 8 4443.26	4443.0	
133	.. ..	.. ..	.. ..	.. ..	......	
134	Br. 2 4445.46	Br. 1 4445.46	Br. 2 4445.79	Br. 2 4446.10	4445.7	
135	F 3 4447.04	.. ..	F 2 4447.42	F 3 4447.55	4447.3	

TABLE III. MEAN WAVE-LENGTHS. CLASS R—Continued.

No.	+42° 2811.			−10° 5057.			+5° 5223.			+20° 5071.			+34° 1929.			−10° 513.		
	Character, intensity, and wave-length			Character, intensity, and wave-length.			Character, intensity, and wave-length.			Character, intensity, and wave-length.			Character, intensity, and wave-length.			Character, intensity, and wave-length.		
136	P	2	4450.79	G	6	4450.23	F	3	4450.43	F	3	4450.75	F	3	4449.84	..	..	....
137	W	4	4455.17	P	2	4454.69	F	3	4455.81	..	..	....	..	..	....	F	4	4454.49
138	..	..	....	P	2	4457.69	..	..	....	P	2	4457.55	..	..	....	..	..	....
139	..	..	....	..	..	....	..	..	....	..	..	....	F	3	4459.55	..	..	....
140	..	..	....	..	..	....	..	..	....	Br.	2	4461.37	..	..	....	..	..	....
141*	W	5	4461.87	F	4	4461.41	F	4	4461.76	..	..	....	P	4	4462.12	F	5	4461.74
142	..	..	....	..	..	....	..	..	....	F	3	4463.95	..	..	....	..	..	....
143	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
144	..	..	....	P	3	4464.06	..	..	....	W	5	4465.14	..	..	....	..	..	....
145	P	2	4466.20	..	..	....	..	..	....	P	2	4466.06	..	..	....	..	..	....
146	F	1	4468.85	F	5	4468.65	..	..	....	..	..	....	..	..	....	..	..	....
147	F	2	4469.80	..	..	....	..	..	....	P	3	4469.46	P	4	4469.57	..	..	....
148	F	1	4470.76	..	..	....	P	2	4470.19	..	..	....	..	..	....	F	6	4470.75
149	..	..	....	P	2	4471.78	..	..	....	..	..	....	..	..	....	..	..	....
150	F	2	4473.58	..	..	....	..	..	....	..	..	....	P	2	4474.82	N	2	4475.86
151*	F	6	4481.39	F	8	4481.11	G	6	4481.08	P	2	4481.73	F	4	4481.30	F	4	4481.48
152	..	..	....	F	3	4484.35	..	..	....	..	..	....	..	..	....	..	..	....
153*	F	4	4489.54	F	6	4489.67	P	4	4489.54	F	4	4489.64	F	3	4489.52	..	..	....
154	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
155	..	..	....	..	..	....	..	..	....	F	2	4491.39	..	..	....	..	..	....
156	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
157	..	..	....	P	3	4494.00	..	..	....	..	..	....	..	..	....	..	..	....
158	W	4	4495.04	..	..	....	G	4	4494.67	..	..	....	W	3	4495.14	F	3	4494.49
159	..	..	....	P	3	4497.08	..	..	....	F	3	4496.70	..	..	....	..	..	....
160	..	..	....	..	..	....	..	..	....	..	..	....	F	4	4498.70	F	3	4498.72
161*	F	4	4501.41	G	9	4501.21	F	4	4501.27	F	2	4501.57	G	4	4501.34	F	4	4501.09
162	..	..	....	Br.	?	4506.92	P	3	4506.45	..	..	....	..	..	....	..	..	....
163	F	3	4507.77	F	3	4508.10	..	..	....	..	..	....	..	..	....	..	..	....
164	..	..	....	..	..	....	..	..	....			4512.35	..	..	....	..	..	....
165	N	6	4513.97	F	8	4514.19	W	8	4513.79	..	..	....	F	7	4513.74	G	6	4514.47
166	..	..	....	..	..	....	..	..	....	..	..	....	P	3	4516.04	..	..	....
167	..	..	....	..	..	....	..	..	....	F	2	4518.38	..	..	....	F	3	4518.28
168			4519.87	F	5	4519.86	F	3	4519.20	..	..	....	..	..	....	..	..	....
169	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
170	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	F	3	4522.29
171	F	2	4523.15	F	4	4522.86			4523.36	..	..	....	..	..	....	..	..	....
172	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
173			4525.50	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
174*	F	3	4526.67	P	4	4527.89	..	..	....	F	4	4526.20	F	3	4526.71	F	4	4526.66
175	Str.		4530.72	P	5	4530.83	W	8	4530.52	..	..	....	..	..	....	F	5	4530.82
176	..	..	....	P	5	4534.36	..	..	....	..	..	....	..	..	....	..	..	....
177			4536.43	..	..	....			4536.03	..	..	....			4536.02	F	3	4536.75
178	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
179	..	..	....	Bl.	3	4540.65	W	4	4540.74	..	..	....	..	..	....	..	..	....
180	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	F	4	4541.23

TABLE III. MEAN WAVE-LENGTHS. CLASS R—Continued.

NO.	+ 61° 667.			− 3° 1685.			+ 57° 702.			+ 14° 2048.			MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			ANGSTROMS.	ELEMENT.
136	F	3	4449.83	F	3	4450.41	F	3	4450.21	F	3	4450.61	4450.3	Ti.
137	..	..	....	N	4	4455.14	W	3	4455.43	F	4	4455.54	4455.2	Ca.
138	..	..	....	..	..	....	..	..	....	..	..	....	......	
139	..	..	....	..	..	....	..	..	....	..	..	....	......	
140	..	..	....	..	..	....	..	..	....	..	..	....	......	
141*	F	4	4461.79	G	7	4461.74	G	7	4461.74	F	6	4462.10	4461.8	Fe.
142	..	..	....	..	..	....	..	..	....	..	..	....	......	
143	Br.	2	4463.40	Br.	2	4464.17	Br.	2	4464.33	Br.	1	4464.01	4464.0	Ti.
144			4464.47	..	..	....	..	..	....	..	..	....	......	
145	F	3	4466.18	..	..	....	F	3	4466.09	F	2	4466.66	4466.2	
146	..	..	....	..	..	....	..	..	....	..	..	....	4468.7	Ti.
147	..	..	....	..	..	....	F	3	4469.28	N	5	4469.94	4469.6	Cr. Fe.
148	..	..	....	..	..	....	..	..	....	..	..	....	4470.7	Ni.
149			4472.02	F	3	4471.21	..	..	....			4471.50	4471.6	
150	F	4	4475.27	F	3	4475.88	F	4	4476.02	F	3	4476.29	......	Fe.
151*	P	5	4481.16	N	3	4481.46	W	3	4481.30	N	4	4482.12	4481.4	Ti. Mag.
152	F	3	4484.74	..	..	....	..	..	....	..	..	....	4484.5	Fe.
153*	F	3	4489.82	..	..	....	..	..	....	..	..	....	4489.7	Cr. Fe.
154	..	..	....	P	3	4490.24	..	..	....	..	..	....	......	
155	..	..	....	..	..	....	..	..	....	F	3	4491.41	4491.4	
156			4493.16	..	..	....	..	..	....	..	..	....	......	
157	..	..	....			4494.03	..	..	....	..	..	....	......	
158	..	..	....	..	..	....	W	5	4495.09	W	5	4495.34	4495.0	Fe.
159			4496 81			4496.20	..	..	....	..	..	....	......	N. V.
160	..	..	....	..	..	....	..	..	....	..	..	....	......	
161*	F	3	4501.51	F	4	4501.32	F	4	4501.39	F	5	4501.88	4501.4	Cr.
162	F	4	4506.67	F	3	4507.28	F	3	4506.83	F	3	4506.96	4506.8	
163	..	..	....	..	..	....	..	..	....	..	..	....	4507.9	
164			4511.08			4511.03	P	3	4511.24			4512.37	......	
165	..	..	....	W	8	4514.07	W	6	4514.42	W	9	4514.09	4514.1	Cy.
166			4515.08			4516.05			4515.20			4516.65	......	
167	..	..	....	..	..	....	..	..	....	F	2	4518.33	......	Ti.
168	..	..	....	..	..	....	..	..	....	..	..	....	......	
169	..	..	....	..	..	....	..	..	....	F	2	4520.31	......	
170	..	..	....	..	..	....	..	..	....	..	..	....	......	
171	F	3	4523.20	F	3	4523.11	F	3	4522.76	F	2	4523.27	4523.1	Ti.
172	..	..	....	Rev.	1	4524.78	Br.	2	4524.55	..	..	....	4524.7	V.
173	..	..	....	..	..	....	S	1	4525.05	..	..	....	......	Cr.
174*	F	6	4526.67	F	3	4526.92			4527.75	F	4	4527.52	4527.0	Ti. Ca.
175	..	..	....	..	..	....	F	3	4531.71	F	5	4531.42	4531.6	Cr. Fe.
176	F	4	4534.49	..	..	....	..	..	....	..	..	....	......	Ti.
177			4536.05			4536.44			4537.08			4537.06	4536.6	Ti.
178	Br.	1	4537.73	Br.	2	4538.20	..	..	....	Br.	3	4538.72	4538.2	
179	..	..	....	..	..	....	..	..	....	..	..	....	......	
180	..	..	....	..	..	....	..	..	....	..	..	....	......	

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811. Character, intensity, and wave-length.			— 10° 5057. Character, intensity, and wave-length.			+ 5° 5223. Character, intensity, and wave-length.			+ 20° 5071. Character, intensity, and wave-length.			+ 34° 1929. Character, intensity, and wave-length.			— 10° 513. Character, intensity, and wave-length.		
181	W	4	4542.20	F	3	4542.18	..	..	....	..	..	....	F	3	4541.55	..	..	....
182	..	..	....	..	..	....	..	..	....	F	4	4544.24	..	..	....	..	..	....
183	F	3	4545.20	F	3	4545.44	P	3	4545.54	..	..	....	F	2	4545.25	F	3	4545.40
184	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
185	..	..	....	..	..	....			4546.30	..	..	....	..	..	....			4548.41
186	..	..	....	..	..	....	..	..	....	W	5	4548.95	..	..	....	..	..	....
187*	F	3	4549.86	F	4	4549.61	F	3	4550.09	..	..	....	F	3	4549.82	P	4	4549.74
188	..	..	....	..	..	....			4551.96	..	..	....	Edge		4553.69	F	5	4552.54
189	F	3	4553.47	F	3	4553.48	..	..	....	..	..	....	..	..	....	..	..	....
190	..	..	....	..	..	....	..	..	....	F	2	4555.27	..	..	....	..	..	....
191	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
192	F	2	4560.77	P	3	4559.96	F	4	4560.38	..	..	....	P	3	4560.52	F	3	4560.69
193	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
194	..	..	....	..	..	....	..	..	....	Br.	1	4563.82	..	..	....	..	..	....
195*	Var.		4564.93	F	6	4564.65	F	3	4564.68	..	..	....	W	5	4564.78	..	..	....
196	..	..	....	..	..	....	..	..	....	F	3	4566.56	..	..	....	..	..	....
197	..	..	....	..	..	....	..	..	....	..	..	....	Br.	1	4567.69	..	..	....
198	..	..	....	..	..	....	..	..	....	..	..	....	F	3	4568.95	..	..	....
199	S	2	4571.85	F	4	4571.81	F	3	4572.26	F	3	4572.23	..	..	....	P	3	4571.85
200	F	3	4576.73	F	3	4576.85	F	3	4577.02	..	..	....	W	6	4576.83	F	6	4576.93
201	P	2	4580.20	P	1	4580.82	F	2	4579.86	..	..	....	F	3	4580.50	F	3	4580.72
202	..	..	....	F	4	4584.19	F	3	4585.51	..	..	....	F	5	4585.48	F	3	4586.73
203	..	..	....	P	3	4587.23	..	..	....	..	..	....	..	..	....	F	2	4588.37
204	..	..	....	..	..	....	Br.	2	4589.33	..	..	....	Br.	1	4590.51	..	..	....
205	P	3	4592.20	F	2	4592.64	..	..	....	..	..	....	..	..	....	..	..	....
206	..	..	....	P	2	4594.80	P	2	4594.33	..	..	....	..	..	....	F	2	4593.80
207	F	3	4596.42	..	..	....	..	..	....	..	..	....			4596.21	..	..	....
208	..	..	....	P	2	4597.03	..	..	....	F	2	4597.58	..	..	....	F	2	4597.19
209	..	..	....	..	..	....	..	..	....	Br. ?	2	4599.37	..	..	....	..	..	....
210	..	..	....	F	3	4601.07	..	..	....	G	4	4601.21	..	..	....	F	4	4601.53
211	..	..	....	P	2	4603.34	P	3	4603.21	..	..	....	..	..	....	..	..	....
212	F	4	4605.51	F	5	4605.78	F	4	4605.52	..	..	....	..	..	....	F	3	4605.81
213	..	..	....	..	..	....	..	..	....	..	..	....			4606.18	..	..	....
214	..	..	....	F	4	4612.67	..	..	....	..	..	....	..	..	....	..	..	....
215	Dif.	3	4613.35	..	..	....	P	3	4613.25	..	..	....	..	..	....	F	3	4613.24
216	..	..	....	P	3	4614.97	..	..	....	..	..	....	..	..	....	..	..	....
217	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
218	F	2	4619.74	F	4	4619.36	F	4	4619.48	..	..	....	..	..	....	..	..	....
219	..	..	....	F	3	4623.43	..	..	....	Dif.	2	4624.29	..	..	....	..	..	....
220	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....	..	..	....
221	W	3	4626.03	F	2	4625.99	P	3	4626.20	..	..	....	..	..	....	..	..	....
222	..	..	....			4628.87	F	3	4628.95	..	..	....	..	..	....	..	..	....
223	..	..	....	F	4	4629.26	..	..	....	..	..	....	..	..	....	..	..	....
224	W	4	4630.10	F	7	4631.26	..	..	....	..	..	....	..	..	....	..	..	....
225	..	..	....	F	6	4633.46	..	..	....	..	..	....	..	..	....	..	..	....

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61 667.			— 3 1685.			+ 57 702.			+ 14 2048.			MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			ANGSTROMS.	ELEMENT.
181	..	..	....	N	4	4541.98	F	3	4542.08	F	3	4542.15	......	
182	..	..	....	..	..	....	..	..	....	..	..	....	......	
183	F	3	4545.66	F	3	4545.74	F	5	4545.30	F	3	4546.07	4545.5	V.
184	Br.	2	4547.80	Br.	2	4547.72	..	..	....	..	..	....	......	
185	..	..	....	..	..	....	..	..	....	..	..	....	......	
186	..	..	....	..	..	....			4548.89	..	..	....	......	
187*	F	3	4549.74	F	3	4549.50	..	..	....	F	4	4550.13	4549.8	V. Ti.
188			4552.03	..	..	....	..	..	....	..	..	....	......	
189	F	10	4552.96	Str.		4552.91	W	7	7452.25	Str.		4552.08	4553.4	Cy.
190			4554.58			4555.00			4553.76			4554.01	4555.	
191	..	..	....			4559.51	..	..	....	..	..	....	......	
192	G	6	4560.42	W	8	4561.60	W	6	4561.43	F	6	4561.11	4560.7	V.
193	..	..	....			4563.91			4563.40	..	..	....	......	
194	..	..	....	..	..	....	..	..	....	..	..	....	......	Ti.
195*	Dif.	4	4564.51	..	..	....	..	..	....	W	3	4565.18	4564.8	Fe.
196	..	..	....	F	2	4566.12	..	..	....	..	..	....	......	
197	Br.	3	4568.00	..	..	....	Br.	1	4567.35	..	..	....	4567.7	
198	..	..	....	..	..	....	..	..	....	..	..	....	......	
199	F	3	4571.87	F	6	4572.00	W	5	4571.95	W	4	4572.00	4571.9	Ti.
200	F	5	4576.40	F	5	4576.45	W	6	4576.43	F	4	4576.75	4576.7	
201	..	..	....	..	..	....	..	..	....	..	..	....	4580.4	Cr.
202	F	6	4586.73	F	3	4587.46	W	4	4586.36	W	4	4587.59	......	
203			4587.56	..	..	....			4588.52	..	..	....	......	
204	..	..	....	..	..	....	Br.	2	4591.01	..	..	....	4589.9	
205	..	..	....	..	..	....	..	..	....	..	..	....	......	Cr.
206	F	2	4593.62	F	3	4593.30	F	3	4592.97	P	2	4593.63	4593.8	V.
207	..	..	....	..	..	....	..	..	....	..	..	....	......	
208	..	..	....	..	..	....	..	..	....	F	2	4597.54	4597.3	
209	..	..	....	..	..	....	..	..	....	..	..	....	......	
210			4601.51	P	4	4601.12	..	..	....	F	3	4601.41	4601.4	Cr. ?
211	..	..	....	..	..	....	..	..	....	W	8	4603.03	4603.2	Fe.
212	..	..	....	..	..	....	W	6	4605.28	..	..	....	4605.6	Cy.
213			4607.25	..	..	....	..	..	....			4606.28	......	
214	..	..	....	..	..	....	..	..	....	..	..	....	......	
215	F	2	4612.98	..	..	....	..	..	....	..	..	....	4613.2	Fe.
216	..	..	....	W	5	4614.57	W	6	4614.55	F	3	4614.68	4614.7	
217	Br.	2	4617.50	..	..	....	..	..	....	..	..	....	......	Ti.
218	..	..	....	P	3	4620.45	..	..	....	..	..	....	4619.7	V.
219	..	..	....	..	..	....	W	4	4623.19	..	..	....	......	
220	..	..	....	..	..	....	..	..	....	F	3	4625.39	......	
221	..	..	....	..	..	....	..	..	....	..	..	....	4626.1	Cr.
222	..	..	....	..	..	....	..	..	....	..	..	....	4628.9	Cr.
223	..	..	....	..	..	....	..	..	....	..	..	....	......	
224	..	..	....	..	..	....	..	..	....	..	..	....	......	
225	Dif.	7	4633.56	..	..	....	W	5	4632.99	F	4	4633.16	4633.3	Fe. Cr.

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811. CHARACTER, INTENSITY, AND WAVE-LENGTH.	— 10° 5057. CHARACTER, INTENSITY, AND WAVE-LENGTH.	+ 5° 5223. CHARACTER, INTENSITY, AND WAVE-LENGTH.	+ 20° 5071. CHARACTER, INTENSITY, AND WAVE-LENGTH.	+ 34° 1929. CHARACTER, INTENSITY, AND WAVE-LENGTH.	— 10° 513. CHARACTER, INTENSITY, AND WAVE-LENGTH.
226	.. ..	.. ..	.. ..	.. ..	.. ..	F 3 4637.14
227	.. ..	F 3 4640.58	F 2 4640.63	W 3 4641.63	.. ..	F 2 4640.18
228	.. ..	Br. 1 4642.75	.. ..	.. ..	.. ..	.. ..
229	P 5 4648.01	F 6 4647.13	W 5 4646.50	.. ..	.. ..	.. ..
230	W 5 4656.55	F 5 4656.52	F 4 4656.54	.. ..	.. ..	.. ..
231	.. ..	.. ..	.. ..	F 2 4658.38	.. ..	.. ..
232	Br. 4660.01	.. ..	.. ..	.. ..	.. ..	.. ..
233	.. ..	.. ..	F 2 4663.23	W 4 4664.73	.. ..	.. ..
234	W 4 4668.10	.. ..	F 4 4668.33	.. ..	.. ..	.. ..
235	Dif. 3 4680.85	.. ..	.. ..	.. ..	.. ..	.. ..
236	.. ..	.. ..	P 3 4684.22	.. ..	.. ..	.. ..
237	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
238	W 3 4696.90	F 4 4696.73	F 4 4698.14	.. ..	P 6 4697.34	.. ..
239	.. ..	.. ..	.. ..	P 4 4699.05	.. ..	.. ..
240	.. ..	.. ..	.. ..	G 6 4709.04	.. ..	.. ..
241	.. ..	.. ..	.. ..	.. ..	.. ..	4713.45
242*	F 7 4715.04	F 10 4714.07	G 9 4714.83	.. ..	F 6 4715.01	F 6 4714.48
243	.. ..	.. ..	.. ..	F 5 4716.87	.. ..	.. ..
244	F 3 4722.68	.. ..	F 4 4722.61	.. ..	F 3 4722.37	F 5 4721.61
245	.. ..	.. ..	.. ..	F 2 4724.29	.. ..	.. ..
246	F 4 4728.83	F 3 4728.77	F 3 4728.79	.. ..	F 3 4728.13	F 3 4727.65
247	.. ..	.. ..	.. ..	G 5 4730.03	.. ..	.. ..
248*	G 4736.36	G 4736.02	G 4636.37	.. ..	G 4736.42	G 10 4736.11
249	.. ..	.. ..	.. ..	G 4738.81	.. ..	.. ..
250	Head 4737.55	Head 4737.47	.. ..	.. ..	Head 4737.27	Head 4737.07
251	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
252	W 7 4743.80	.. ..	F 6 4743.74	.. ..	G 7 4743.65	G 8 4743.66
253	Edge 4745.59	F 2 4745.86	Edge 4744.40	.. ..	Edge 4744.66	Edge 4744.80
254	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
255	F 1 4748.78	.. ..	.. ..	.. ..	.. ..	.. ..
256	.. ..	.. ..	.. ..	.. ..	F 3 4750.62	F 4 4750.99
257	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
258	F 2 4755.50	F 2 4756.30	.. ..	.. ..	F 3 4754.94	.. ..
259	.. ..	.. ..	.. ..	.. ..	F 2 4757.17	.. ..
260	.. ..	.. ..	.. ..	.. ..	.. ..	4761.79
261	F 1 4762.25	S 2 4762.50	.. ..	.. ..	.. ..	.. ..
262	.. ..	F 4 4763.78	.. ..	.. ..	4762.97	.. ..
263	W 5 4765.13	F 3 4765.46	W 4 4765.06	.. ..	W 3 4765.95	W 3 4764.06
264	.. ..	.. ..	.. ..	.. ..	4767.66	.. ..
265	.. ..	G 3 4771.37	.. ..	.. ..	.. ..	.. ..
266	Dif. 2 4772.42	.. ..	P 2 4772.18	.. ..	.. ..	4772.33
267	.. ..	F 2 4775.88	F 3 4775.24	.. ..	.. ..	.. ..
268	.. ..	.. ..	4780.25	.. ..	.. ..	.. ..
269	4783.57	P 3 4783.45	.. ..	F 2 4783.19	F 3 4784.24	.. ..
270	W 5 4787.63	F 3 4786.30	.. ..	.. ..	.. ..	.. ..

TABLE III. MEAN WAVE-LENGTHS. CLASS K—CONTINUED.

NO.	+ 61° 667. Character, Intensity, and Wave-length.	− 3° 1685. Character, Intensity, and Wave-length.	+ 57° 702. Character, Intensity, and Wave-length.	+ 14° 2048. Character, Intensity, and Wave-length.	Mean and Identification. Angstroms.	Element.
226	F 3 4637.16	P 3 4636.68	.. ..	.. ..	4637.0	Ca.
227	F 3 4640.64	.. ..	.. ..	.. ..	4640.7	
228	Br. 2 4643.08	.. ..	.. ..	.. ..	4642.9	
229	.. ..	.. ..	.. ..	F 3 4645.96	......	
230	.. ..	F 3 4656.88	.. ..	.. ..	4656.6	Ti. Cr.
231	.. ..	.. ..	.. ..	.. ..	......	
232	.. ..	.. ..	.. ..	.. ..	......	
233	.. ..	.. ..	.. ..	.. ..	......	
234	.. ..	.. ..	.. ..	.. ..	4668.2	Fe.
235	.. ..	.. ..	.. ..	.. ..	......	
236	.. ..	.. ..	.. ..	.. ..	......	
237	F 4 4694.24	.. ..	.. ..	.. ..	......	
238	.. ..	.. ..	.. ..	.. ..	4697.2	C.
239	.. ..	.. ..	.. ..	.. ..	......	
240	.. ..	.. ..	.. ..	.. ..	......	
141	.. ..	.. ..	.. ..	.. ..	......	
242*	F 6 4715.18	.. ..	.. ..	.. ..	4714.8	C. Ni.
243	.. ..	.. ..	.. ..	.. ..	......	
244	F 6 4722.43	.. ..	.. ..	.. ..	4722.3	Zn.
245	.. ..	.. ..	.. ..	.. ..	......	
246	.. ..	P 3 4729.17	.. ..	.. ..	4728.6	Fe.
247	.. ..	.. ..	.. ..	.. ..	......	
248*	F 6 4736.62	F 6 4736.59	F 6 4736.56	W 6 4736.90	4736.4	C.
249	.. ..	.. ..	.. ..	.. ..	......	
250	Head 4737.70	Head 4737.67	.. ..	Head 4737.92	4737.6	Cr.
251	Br. 3 4739.71	.. ..	.. ..	Br. 2 4739.61	4739.7	
252	G 10 4743.60	G 10 4743.17	G 10 4743.20	G 10 4743.60	4743.6	
253	Edge 4745.40	Edge 4745.11	Edge 4745.14	4745.14	4745.1	
254	Br. 2 4747.63	Br. 3 4747.46	.. ..	Br. 3 4747.78	4747.6	
255	.. ..	.. ..	.. ..	.. ..	......	
256	F 6 4751.51	G 10 4751.02	G 10 4751.05	G 9 4751.51	4751.1	
257	Edge 4753.31	Edge 4752.45	Edge 4752.91	Edge 4752.51	4752.8	
258	.. ..	Br. 3 4755.32	.. ..	.. ..	......	
259	.. ..	F 3 4758.38	F 2 4757.83	F 2 4758.58	4758.0	
260	.. ..	.. ..	.. ..	.. ..	......	
261	.. ..	.. ..	.. ..	.. ..	4762.4	
262	.. ..	.. ..	.. ..	.. ..	......	
263	.. ..	.. ..	.. ..	.. ..	4765.3	
264	Neb. 4766.51	F 3 4765.98	W 3 4764.79	P 2 4765.92	......	
265	.. ..	.. ..	.. ..	.. ..	......	
266	F 3 4772.30	F 2 4772.30	F 2 4772.30	P 3 4772.91	4772.4	
267	Br. 2 4777.85	.. ..	Br. 2 4775.26	.. ..	......	
268	4780.15	.. ..	.. ..	.. ..	......	
269	.. ..	.. ..	F 3 4784.77	.. ..	......	
270	Neb. 4 4787.23	W 5 4787.02	.. ..	F 4786.65	......	

TABLE III. MEAN WAVE-LENGTHS. CLASS R—Continued.

No.	+ 42° 2811.	— 10° 5057.	+ 5° 5223.	+ 20° 5071.	+ 34° 1929.	— 10° 513.
	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.	Character, intensity, and wave-length.
271	4793.17	P 3 4792.40	4792.04	..	..	F 3 4793.59
272	..	..	..	..	..	..
273	F 3 4799.52	F 3 4799.09	F 4 4799.40	..	F 3 4799.42	..
274	..	..	..	..	..	W 3 4801.28
275	..	..	..	..	..	..
276	..	P 3 4804.80	..	..	..	..
277	Dif. 3 4807.86	..	..	..	..	..
278	4809.90	..	..	..	..	..
279	..	P 2 4811.78	..	..	..	..
280	..	..	..	..	..	..
281	..	P 3 4817.03	..	..	..	..
282	..	..	..	P 2 4818.90	..	..
283	..	..	F 3 4823.74	..	..	F 2 4822.73
284	W 3 4824.05	P 3 4824.72	..	..	..	..
285	..	P 3 4826.66	..	..	..	..
286	..	P 2 4828.89	..	..	..	..
287	P 3 4833.00	..	F 3 4833.08	..	..	..
288	..	F 4 4836.83	F 3 4838.60	..	F 3 4838.18	F 3 4839.31
289	Dif. 3 4841.41	..	..	..	F 3 4841.94	P 4 4841.77
290	..	P 2 4843.75	..	..	..	F 1 4844.14
291	..	..	..	..	..	..
292	F 2 4848.64	F 3 4848.76	F 3 4848.86	..	..	..
293	F 4 4855.85	F 4 4855.05	..	G 5 4856.32	P 2 4855.54	F 2 4855.86
294*	G 5 4861.39	..	F 4 4860.60	F 1 4861.34	F 2 4861.26	F 5 4861.42
295	..	P 2 4865.81	..	F 2 4866.64	Br. 1 4866.67	..
296	..	..	..	..	..	F 2 4868.40
297	4870.29	..	..	..	..	..
298*	..	F 4 4871.41	F 4 4871.88	F 2 4871.67	Dif. 3 4872.31	F 2 4872.08
299	..	..	..	..	..	..
300	..	P 3 4875.54	..	..	..	..
301	4877.14	..	..	..	..	F 3 4877.95
302	..	F 3 4881.29	..	..	..	..
303	4884.60	..	..	..	..	..
304*	W 3 4886.07	F 4 4886.23	F 3 4886.10	W 4 4886.12	F 5 4885.95	F 4 4886.49
305	..	P 2 4889.28	..	..	..	..
306	4892.80	..	F 3 4892.05	..	Dif. 4 4892.60	F 3 4892.05
307	..	..	..	..	..	..
308	..	..	..	F 3 4896.82	..	..
309	..	F 3 4900.79	..	..	G 4 4900.14	..
310	..	..	F 2 4903.43	..	..	..
311	..	..	..	F 3 4905.54	..	..
312	F 3 4911.07	F 4 4910.69	F 3 4911.12	..	..	..
313	..	..	..	P 4 4915.81	..	..
314	4917.85	..	..	..	..	..
315	Str. 4920.98	G 7 4922.32	G 4 4920.58	..	F 4 4921.70	F 4 4920.67

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

No.	+ 61° 667.			− 3° 1685.			+ 57° 702.			+ 14° 2048.			Mean and Identification.	
	Character, Intensity, and Wave-length.			Character, Intensity, and Wave-length.			Character, Intensity, and Wave-length.			Character, Intensity, and Wave-length.			Angstroms.	Element.
271			4792.20 }	F	2	4793.53 }	..	..	....	..	..	....	......	
272	Br.	2	4795.21	..	..	....	..	..	....	..	..	....	......	
273	W	4	4799.34	F	4	4798.09	F	3	4798.84	W	3	4799.64	4799.3	
274	..	..	....	..	..	....	..	..	....	..	..	....	......	
275	Br.	2	4803.00	..	..	....	..	..	....	..	..	....	......	
276	..	..	....	W	2	4805.81	..	..	....	..	..	....	......	
277	..	..	....	..	..	....	..	..	....	..	..	....	......	
278	..	..	....	..	..	....	..	..	....	..	..	....	......	
279	F	3	4811.45	Br.	1	4811.23	..	..	....	..	..	....	4811.5	
280	..	..	....	F	2	4816.46	..	..	....	F	3	4815.50	4816.5	
281	..	..	....	..	..	....	..	..	....	..	..	....	......	
282	Br.	2	4818.15	Br.	2	4819.32	Br.	2	4818.72	Br.	3	4820.22	......	
283	F	4	4823.28	F	4	4822.57	F	2	4822.70	F	4	4822.52	4822.9	
284	..	..	....	..	..	....	..	..	....	..	..	....	......	
285	..	..	....	..	..	....	..	..	....	..	..	....	......	
286	..	..	....	F	2	4827.16	F	2	4828.32	F	3	4828.58	4828.2	V.
287	F	4	4832.57	F	2	4832.19	F	2	4833.24	F	2	4833.00	4832.8	Fe.
288	..	..	....	G	5	4839.40	..	..	....	..	..	....	......	
289	F	3	4842.89	..	..	....	..	..	....	..	..	....	......	
290	..	..	....	G	6	4843.10	F	3	4843.69	F	3	4843.38	4843.6	
291	..	..	....	W	4	4845.58	..	..	....	..	..	....	......	
292	F	2	4848.78	..	..	....	..	..	....	S	2	4847.72	4848.6	
293	F	3	4855.64	F	4	4854.46	F	3	4854.74	P	2	4854.95	4855.4	
294*	W	3	4861.14	W	5	4860.91	F	3	4861.38	W	4	4862.35	4861.3	$H\beta$.
295	S	1	4865.68	..	..	....	P	2	4866.58	..	..	....	......	Ni. ?
296	..	..	....	..	..	....	Br.	2	4868.62	..	..	....	......	
297	..	..	....	..	..	....	..	..	....	..	..	....	......	
298*	..	..	....	P	2	4871.77	F	1	4872.15	..	..	....	4871.9	V. Fe.
299	F	3	4875.15	..	..	....	..	..	....	..	..	....	......	
300	..	..	....	F	3	4875.25	F	4	4875.90	F	3	4875.77	4875.7	V.
301	..	..	....	..	..	....	..	..	....	..	..	....	......	
302	..	..	....	F	3	4881.34	F	3	4881.09	F	2	4881.25	4881.2	V. ?
303	..	..	....	..	..	....	..	..	....	..	..	....	......	
304*	W	4	4886.29	F	3	4886.23	F	4	4886.20	G	3	4886.57	4886.2	Fe. V.
305	..	..	....	..	..	....	..	..	....	..	..	....	......	
306	F	5	4891.51	F	4	4891.01	F	2	4890.85	..	..	....	......	V.
307	Edge		4892.13	..	..	....	..	..	....	..	..	....	......	
308	Br.	2	4896.52	..	..	....	F	3	4896.78	..	..	....	......	
309	..	..	....	Br.	2	4898.29	..	..	....	Br.	2	4899.51	......	
310	F	5	4902.89	F	3	4901.69	F	3	4901.08	..	..	....	......	
311	..	..	....	F	3	4905.74	F	2	4906.64	..	..	....	4906.0	V.
312	..	..	....	F	4	4910.07	W	4	4911.33	F	4	4910.91	4911.0	Fe.
313	..	..	....	..	..	....	..	..	....	..	..	....	......	
314	..	..	....	..	..	....	..	..	....	..	..	....	......	
315	G	5	4920.12	G	7	4921.31	W	5	4919.72	F	4	4921.64	4921.0	Fe.

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811.	— 10° 5057.	+ 5° 5223.	+ 20° 5071.	+ 34° 1929.	— 10° 513.
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.
316	4926.11 j	.. ..	.. ..	.. ..	.. ..	.. ..
317	.. ..	F 3 4933.77	.. ..	F 6 4931.06	.. ..	.. ..
318	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
319	W 4 4939.01	P 4 3937.84	P 2 3940.21	.. ..	.. ..	F 4 3938.19
320	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
321	F 4 4957.86	F 3 4957.77	F 4 4958.20	.. ..	.. ..	.. ..
322	.. ..	.. ..	F 3 4965.73	.. ..	.. ..	.. ..
323	Dif. 2 4969.74	.. ..	.. ..	.. ..	.. ..	.. ..
324	.. ..	.. ..	F 2 4978.07	.. ..	.. ..	.. ..
325	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
326	W 5 4984.09	G 4 4983.19	F 4 4984.06	F 5 4985.68	.. ..	P 3 4984.96
327	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
328	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
329	F 4 5006.89	.. ..	F 3 5006.70	.. ..	.. ..	.. ..

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.	− 3° 1685.	+ 57° 702.	+ 14° 2048.	MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	ANGSTROMS.	ELEMENT.
316	.. ..	.. ..	.. ..	.. ..	......	
317	.. ..	F 2 4929.76	.. ..	.. ..	......	
318	.. ..	F 2 4932.25	.. ..	.. ..	......	
319	.. ..	F 6 3936.63	W 4 3937.69	W 4 3935.74	......	
320	.. ..	3954.39	.. ..	.. ..	......	
321	.. ..	.. ..	.. ..	W 3 4958.94	4958.2	Fe.
322	.. ..	.. ..	.. ..	.. ..	......	
323	.. ..	4068.77	.. ..	F 3 4068.38	......	
324	.. ..	W 6 4977.62	F 4 4077.85	.. ..	4977.8	Ti. Fe.
325	.. ..	Rev. 1 4982.08	Br. 1 4982.22	.. ..	4982.1	Ti.
326	.. ..	F 6 4985.74	F 6 4986.63	W 5 4987.49	......	
327	.. ..	4990.65	.. ..	.. ..	......	
328	.. ..	F 3 5000.61	F 5 5001.20	.. ..	......	
329	.. ..	.. ..	.. ..	.. ..	......	

TABLE IV. WAVE-LENGTHS. CLASS X.

NO.	19 PISCIUM. CHARACTER, INTENSITY, AND WAVE-LENGTH.			+ 76° 734. CHARACTER, INTENSITY, AND WAVE-LENGTH.			+ 34° 4500. CHARACTER, INTENSITY, AND WAVE-LENGTH.		
1	End		4242.98	..	..	....	..	..	....
2	P	5	4247.68	..	..	....	..	..	....
3	F	1	4251.08	..	..	....	..	..	....
4	P	5	4254.12	..	..	....	..	..	....
5	P	6	4258.86	..	..	....	..	..	....
6	P	2	4260.69	..	..	....	..	..	....
7	F	5	4262.94	..	..	....	..	..	....
8	F	4	4271.91	..	..	....	..	..	....
9	F	6	4275.41	..	..	....	..	..	....
10	F	4	4277.70	..	..	....	..	..	....
11	Br.	2	4278.74	..	..	....	..	..	....
12	F	3	4280.81	..	..	....	..	..	....
13	F	3	4283.10	..	..	....	..	..	....
14			4288.52	..	..	....	..	..	....
15	F	6	4289.37	..	..	....	..	..	....
16	F	3	4291.90	..	..	....	..	..	....
17			4292.50	..	..	....	..	..	....
18	F	3	4294.93	..	..	....	..	..	....
19	G	6	4307.00	F	6	4306.70	P	5	4307.39
20	F	3	4319.04	F	4	4318.82	..	..	....
21	P	3	4321.51	..	..	....	..	..	....
22	G	10	4325.47	..	..	....	F	7	4325.59
23	F	3	4330.13	..	..	....	..	..	....
24	P	3	4333.85	..	..	....	P	4	4334.05
25	F	2	4337.76	P	4	4338.28	F	5	4339.22
26	Br. ?		4339.62	..	..	....	..	..	....
27	F	2	4341.70	..	..	....	..	..	....
28	..	..		..	..	....	P	3	4346.22
29	G	3	4348.06	F	4	4347.53	F	4	4347.98
30	G	8	4351.90	..	..	....	F	6	4351.96
31	F	3	4355.97	..	..	....	..	..	....
32	F	9	4360.46	..	..	....	W	5	4360.38
33			4365.16	..	..	....	..	..	....
34	F	6	4368.48	..	..	....	W	5	4368.37
35	F	1	4373.13	..	..	....	..	..	....
36	F	3	4376.09	F	4	4375.78	F	4	4375.94
37	Br.	1	4377.98	..	..	....	..	..	....
38	F	5	4380.64	..	..	....	..	..	....
39	G	7	4384.50	F	8	4384.21	..	..	....
40	..	..				4385.27	Head		4385.42
41	..	..	....	G	3	4387.44	..	..	....
42	F	4	4390.27	F	5	4390.04	F	4	4390.44
43	G	8	4395.01	F	7	4394.99	F	7	4394.86
44	..	..	....	..	..	....	Br.		4402.62
45	F	5	4400.56	F	6	4400.30	F	8	4400.29

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCIUM.			+ 76 734.			+ 34 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
46	G	6	4404.92	G	8	4404.86	F	7	4405.19
47	F	5	4408.62	F	6	4408.47	F	5	4408.64
48	P	2	4412.61	F	3	4412.01	..	..	....
49	F	4	4415.31	..	..	....	F	4	4415.53
50	..	..	....	P	6	4416.37	..	..	....
51	F	4	4417.34	..	..	....	..	..	....
52	F	3	4420.95	..	..	....	..	..	....
53	..	..	....	F	6	4422.26	F	5	4422.16
54	P	2	4423.21	..	..	....	..	..	....
55	F	1	4426.10	..	..	....	..	..	....
56	F	3	4428.00	..	..	....	G	4	4427.65
57	F	3	4430.05	F	4	4429.74	F	3	4430.33
58	Br.	1	4432.34	..	..	....	Br.		4432.71
59	G	7	4435.46	G	10	4435.48	G	8	4435.72
60	..	..	....	..	..	....	F	2	4438.59
61	..	..	....	..	..	....	Br.		4439.56
62	F	4	4443.43	W	7	4444.03	W	6	4443.08
63	..	..	....	..	..	....	F	2	4447.44
64	F	4	4450.36	F	6	4450.25	G	5	4450.40
65	F	4	4455.80	P	6	4455.20	P	4	4455.98
66	F	2	4459.72	..	..	....	..	..	....
67	F	4	4462.04	F	7	4462.11	F	6	4462.11
68	Br.		4463.95	..	..	....	Br.		4464.33
69	F	2	4465.70	F	5	4465.86			4465.61
70	P	3	4468.64	F	4	4468.84	..	..	....
71	P	3	4471.50	..	..	....	..	..	....
72	..	..	....	..	..	....			4472.21
73	..	..	....	..	..	....	Br.		4473.04
74	P	3	4476.39	F	4	4476.18	..	..	....
75	P	4	4480.23	F	7	4480.53	F	7	4480.39
76	..	..	....	..	..	....	F	3	4487.47
77	F	4	4489.60	P	6	4489.18	F	4	4489.58
78	F	1	4493.80	F	2	4494.50	..	..	....
79	G	6	4496.97	G	6	4496.83	G	7	4496.92
80	F	3	4501.51	F	4	4501.65	F	5	4501.44
81	Br.		4501.81	..	..	....	Edge		4501.90
82	G	4	4506.88	F	5	4506.81	F	5	4507.00
83	P	4	4513.04	F	6	4512.83	W	6	4513.70
84	F	3	4518.47	P	5	4518.63	F	3	4518.63
85	..	..	....	F	2	4520.10	..	..	....
86	F	3	4523.30	G	5	4522.97	G	4	4523.30
87	..	..	....	..	..	....			4526.06
88	F	4	4527.87	F	6	4527.31	P	6	4528.17
89	P	2	4531.45	..	..	....	..	..	....
90	P	5	4535.47	G	8	4535.28	..	..	......

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCIUM.			+ 76° 734.			+ 34° 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
91	..	..	....	..	..	....	Edge		4536.34
92	Br.	2	4538.14	..	..	....	..	..	....
93	G	4	4540.71	F	5	4540.95	F	5	4541.27
94	F	3	4545.81	F	4	4545.74	G	5	4545.93
95	..	..	....	G	3	4549.11	..	..	....
96	F	3	4549.72	..	..	....	F	6	4549.93
97	G	10	4553.85	F	9	4553.34	G	10	4553.61
98	P	3	4560.04	F	4	4560.26	F	3	4560.16
99	P	3	4563.44	..	..	....	F	4	4563.39
100	W	4	4564.68	P	4	4564.06	..	..	....
101	F	1	4565.10	..	..	....	..	..	....
102	..	..	....			4570.34	..	..	....
103	..	..	....	..	..	....			4571.12
104			4571.92	..	..	....	..	..	....
105			4576.78			4577.20			4578.26
106	..	..	....	F	4	4590.86	..	..	....
107	..	..	....	F	2	4593.94	F	4	4593.74
108	..	..	....	F	1	4597.37	F	3	4598.10
109	..	..	....	P	2	4600.58	..	..	....
110	..	..	....	F	1	4603.18	..	..	....
111	G	10	4606.72	G	10	4606.60	G Max.		4606.25
112	..	..	....	F	1	4610.45	..	..	....
113	..	..	....	F	2	4613.45	F	4	4613.75
114	F	2	4616.48	F	2	4616.22	F	4	4616.84
115	F	3	4619.96	G	4	4619.52	G	6	4620.06
116	..	..	....	..	..	....	F	3	4623.12
117	F	3	4629.38	W	4	4629.12	F	4	4629.56
118			4632.61	..	..	....			4632.14
119	..	..	....	W	6	4635.30	..	..	....
120			4637.35	..	..	....			4637.59
121	G	5	4640.47	G	5	4640.29	G	6	4640.65
122	Br.	2	4642.22	..	..	....	Br.		4642.67
123	..	..	....			4644.03			4644.11
124	W	7	4646.55	F	8	4646.28	..	..	....
125	F	6	4656.94	F	6	4657.18	F	5	4657.15
126	W	5	4663.34	..	..	....	F	3	4663.55
127	W	7	4668.85	F	5	4668.04	F	6	4668.77
128	..	..	....	F	4	4682.27	..	..	....
129	..	..	....	..	..	....	W	8	4695.78
130	..	..	....			4698.21	..	..	....
131	F	3	4704.04	F	3	4704.40	..	..	....
132	P	4	4707.42	..	..	....	..	..	....
133	G	9	4714.62	F	8	4714.43	G	10	4714.14
134	F	2	4722.97	F	6	4722.83	F	3	4722.88
135	F	3	4729.43	..	..	....	..	..	....

TABLE IV. WAVE-LENGTHS. CLASS N—Continued.

No.	19 Piscium.			+76° 734			+34° 4500.		
	Character, intensity, and wave-length.			Character, intensity, and wave-length.			Character, intensity, and wave-length.		
136	G	10	4735.96	G	10	4735.87	G	10	4735.96
137	Head		4736.82	Head		4737.11	..	..	....
138	F	6	4743.79	G	9	4743.52	G	10	4743.76
139	..	..	....	F	4	4745.67	..	..	....
140	..	..	....	F	2	4758.67	..	..	....
141	..	..	....	F	1	4761.49	F	2	4763.52
142	..	..	....	F	4	4772.43	P	2	4773.29
143	..	..	....	F	3	4779.33	..	..	....
144	..	..	....			4782.33	..	..	....
145	Neb.		4784.59	W	5	4784.75	..	..	....
146	..	..	....			4789.54	P	2	4789.45
147	..	..	....	F	3	4791.18	..	..	....
148	..	..	....	Dif.	4	4799.69	..	..	....
149	..	..	....	P	3	4805.75	W	4	4806.84
150	..	..	....	..	..	....	F	2	4812.13
151	F	2	4816.03	G	4	4815.82	F	3	4816.24
152	P	2	4823.50	F	5	4822.80	F	4	4823.44
153	..	..	....	F	4	4827.82	F	3	4828.36
154	P	2	4832.72	F	5	4832.54	G	3	4833.00
155	..	..	....	F	3	4839.82	..	..	....
156	..	..	....	P	2	4848.93	..	..	....
157	..	..	....	F	3	4852.18	..	..	....
158	..	..	....	F	4	4854.78	P	4	4854.28
159	Head		4855.37	..	..	....	..	..	....
160	..	..	....	W	4	4865.66	F	3	4865.47
161	..	..	....	..	..	....	F	2	4868.48
162	F	2	4871.74	..	..	....	F	3	4872.02
163	P	2	4874.92	F	4	4875.54	F	3	4876.03
164	F	2	4881.46	G	4	4881.74	F	3	4882.13
165	F	1	4885.40	..	..	....	..	..	....
166	..	..	....	P	4	4891.02	W	4	4891.43
167	..	..	....	F	3	4900.72	..	..	....
168	..	..	....	..	..	....	F	4	4902.77
169	..	..	....	P	3	4905.33	..	..	....
170	..	..	....	F	2	4910.28	..	..	....
171	..	..	....	P	4	4914.40	..	..	....
172	Red Edge		4914.50	..	..	....	..	..	....
173	F	3	4921.44	G	4	4920.73	G	6	4921.12
174	F	4	4934.35	F	4	4934.22	F	6	4934.64
175	P	3	4940.12	..	..	....	..	..	....
176	..	..	....	..	..	....	F	3	4950.18
177	..	..	....	P	4	4957.16	F	3	4958.57
178	..	..	....	F	4	4966.86	..	..	....
179	P	4	4981.39	F	5	4980.33	P	2	4982.35
180	..	..	....	F	4	4986.42	..	..	....

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCIUM. Character, intensity, and wave-length.			+76° 734. Character, intensity, and wave-length.			+34° 4500. Character, intensity, and wave-length.		
181	W	5	4988.20	..	..	....	..	..	....
182	..	..	....	F	4	4990.08	..	..	....
183	W	5	5006.56	F	4	4999.63	F	4	5000.70
184	F	4	5014.76	F	5	5014.44	F	3	5014.62
185	..	..	....	F	6	5038.96	..	..	....
186	Red Edge		5041.30	..	..	....	..	..	....
187	..	..	....	F	7	5095.29	..	..	....
188	..	..	....	Red Edge		5167.95	..	..	....
189	..	..	....	F	6	5182.71	..	..	....
190	..	..	....	F	3	5192.91	..	..	....
191	..	..	....	W	8	5205.82	..	..	....

RADIAL VELOCITIES

The accompanying table (Table V) of radial velocities contains the results obtained for 10 stars belonging to Class R. Although the list is not large enough to give more than an indication of the average radial velocity of the class, it furnishes the only data available at the present time.

Column 1 gives the star's designation; column 2, the plate numbers. The third column gives the quality of the stellar spectrum, S, and of the comparison spectrum, C, of the plate; G, good; F, fair; P, poor; W, wide; and Dif., diffuse. Column 4 contains the number of the lines used in each plate. The radial velocities determined from the individual plates and reduced to the sun are recorded in column 5, also the probable error based upon the internal agreement of the velocities given by the lines used in the reduction of the plate. Column 6 gives the adopted radial velocity of the star reduced to the sun and its probable error. The last column tabulates the residual radial velocity after deducting the component due to the motion of the sun through space, or the radial velocity of the star reduced to the sidereal system.

The number of lines for radial velocity determination of star — 10° 5057 recorded in the table is smaller than the number available for use on the individual plates, as only the lines giving the best results on all the plates were included. Making use of 27 lines of plate 2882 A, 30 lines of plate 2997 A, 31 lines of plate 2914 A, and 32 lines of plate 2915 A, the result gives practical agreement with the value given in the table. The star + 20° 5071 presented some difficulty on account of its broad absorption lines and the presence of bright lines near some of the lines of the standard table. The probable error of the velocity of this star indicates that the close agreement of the separate velocities derived from the three plates is in a measure fortuitous. The relative velocity of this star with reference to — 10° 5057 was determined by comparing the displacements of 20 lines in common and gave good agreement with the tabulated values.

The radial velocity for each star was obtained by weighting the plate velocities according to probable error and the quality of the plate. On account of the small number of available plates for each star, the probable error accompanying the adopted value of the radial velocity of the star was based upon the internal agreement of the lines of the individual plates instead of following the ordinary method of forming residuals from the mean velocity. For the determination of the residual radial velocities the apex of the sun's way was taken at the point, $\alpha = 270°$, $\delta = +30°$, and the velocity of the sun with reference to the sidereal system was taken to be 20 km. per sec. This is the position of the apex of the sun's way and value of the velocity of the sun through space favored by Boss for general use

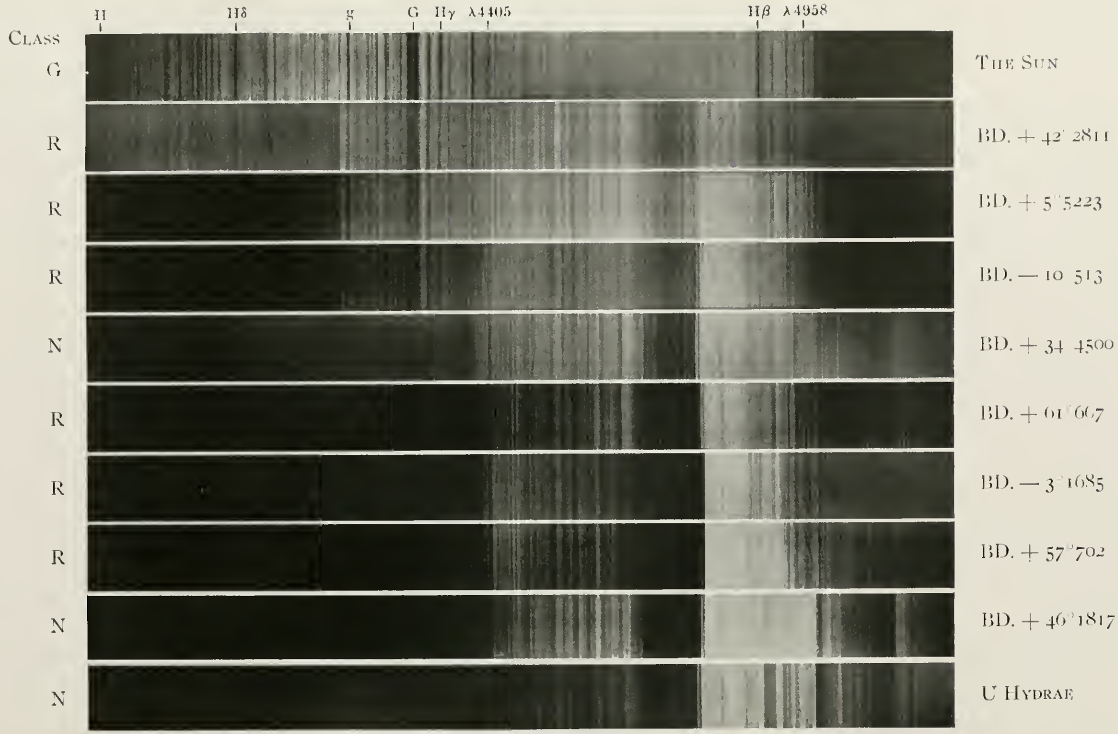

Plate I. Stellar Spectra Illustrating Steps in the Transition from the Sun to Standard Class N

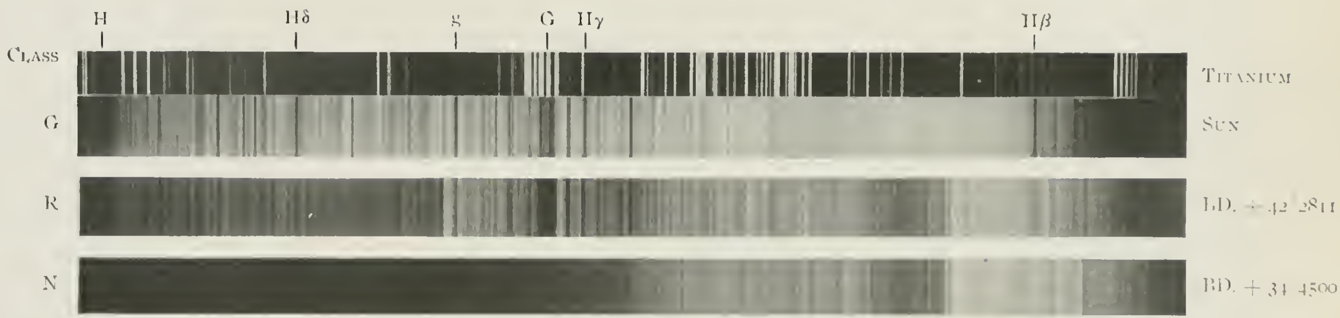

Plate J. Class G, Early Class R, and Early Class N Spectra, with Titanium Spark Comparison

TABLE V. RADIAL VELOCITIES, CLASS R.

STAR.	PLATE.	QUALITY.		NO. OF LINES.	PLATE VELOCITY TO SUN.	STAR VELOCITY TO SUN.	RESIDUAL RADIAL VELOCITY.
		S.	C.				
DM. + 42° 2811	3128 B	F	F	32	− 24.5 ± 1.3		
	3135 B	G	F	33	− 26.0 ± 1.0		
	3144 B	G	G	37	− 25.2 ± 1.2	− 25.2 ± 0.8	− 6.
− 10 5057	2882 A	G	F	17	− 43.2 ± 1.7		
	2887 A	G	G	18	− 42.5 ± 1.3		
	2914 A	G	G	20	− 42.6 ± 1.3		
	2915 A	G	G	21	− 45.0 ± 0.6		
	2923 A	P	F	14	− 43.6 ± 4.3	− 43.8 ± 0.5	− 30.
− 5 5223	2988 A	F	G	26	− 26.0 ± 1.5		
	2989 B	F	F	26	− 26.4 ± 2.2	− 26. ± 1.1	− 24.
+ 20 5071	2966 C	F	G	19	− 49.8 ± 1.6		
	Remeasured.				− 48.4 ± 2.2		
	2967 A	D	F	12	− 48.8 ± 5.2		
	2968 A	P	F	14	− 50.1 ± 4.1	− 49. ± 2.	− 38.
+ 34 1929	3138 B	F	P	33	+ 27.8 ± 1.6		
	3143 A	W	G	26	+ 22.6 ± 1.5	+ 25. ± 1.	+ 20.
− 10 513	3055 A	P	F	12	+ 21.9 ± 3.9		
	3063 A	F	G	24	+ 19.8 ± 1.2	+ 21. ± 1.	+ 9.
+ 61 667	3054 C	F	G	16	− 6.9 ± 1.4		
	3088 A	W	F	7	− 4.1 ± 3.5		
	3089 A	F	F	21	− 8.8 ± 2.1	− 7. ± 1.	− 6.
− 3 1685	3094 D	G	F	25	+ 19.0 ± 1.8		
	3097 A	F	G	27	+ 17.6 ± 2.0	+ 18. ± 1.	+ 1.
+ 57 702	3044 A	W	G	16	− 13.6 ± 2.6		
	3079 A	G	F	29	− 10.6 ± 1.5	− 11. ± 1.	− 10.
+ 14 2048	3126 A	F	G	21	+ 3.5 ± 1.3		
	3127 A	G	G	16	+ 5.9 ± 2.1		
	3134 A	G	G	19	+ 2.6 ± 1.8	+ 4. ± 1.	− 5.
Average velocities considered positive						23. ± 1.	14.9

and represents a compromise between the results obtained by proper motion and radial velocity determination. (*Astr. Jour. 28*, 167, 1914.) This direction was used by Campbell in his solution for solar motion by spectral types (*Lick Observatory Bulletin*, No. 196, 127, 1911.)

At the foot of the columns are given the averages of the radial velocities of Class R stars, 23 km. per second, and of the residual radial velocities, 15 km. per second. In this connection it is interesting to compare the average radial velocity of 8 stars of Class N determined by Hale, Ellerman, and Parkhurst and exhibited in Table VI. The average radial velocity of 8 Class N stars is 11 km. per second. The residual radial velocities were not given in their paper, but were determined by the method given above for the sake of comparison with the results for Class R stars. The average *residual radial velocity* of 8 stars with spectra of Class N is 13 km. per second. On account of the small number of stars of Classes R and N for which the radial velocities have been

determined, their averages may only approximately represent the classes.

Average residual radial velocity of 10 Class R stars, 15 km. per sec.

Average residual radial velocity of 8 Class N stars, 13 km. per sec.

TABLE VI. RADIAL VELOCITIES, CLASS N.

STAR.	RADIAL VELOCITY	RESIDUAL RADIAL VELOCITY.
74 Schj.	+ 5 km.	— 9 km.
78 Schj.	— 1	— 8
115 Schj.	— 13	— 22
132 Schj.	— 28	— 38
318 Birm.	— 10	— 3
152 Schj.	+ 1	+ 10
19 Piscium	— 2	0
280 Schj.	— 25	— 16
Average (positive)	11	13.2

For the sake of comparison with other types the following table is inserted. Part of the data is taken from *Lick Observatory Bulletin*, No. 196, 126, 1911. The values for Classes R and N were added by the writer.

TABLE VII. RESIDUAL RADIAL VELOCITIES ACCORDING TO SPECTRAL TYPE.

SPECTRAL TYPES.	NO. OF STARS.	AVERAGE RESIDUAL RADIAL VELOCITY.
O and B	141	8.99
A	133	9.94
F	159	13.90
G and K	529	15.15
M	72	16.55
R	10	14.9
N	8	13.2

QUALITATIVE RESULTS

General Characteristics. The general features of the spectrum of Class R stars have been given in the section on spectrograms; here we shall discuss the details at greater length.

The most conspicuous feature of the region of the spectrum under consideration (violet end to λ 5000), as previously pointed out, is the broad absorption band with head at λ 4737, usually attributed to some form of carbon compound. The progression of intensity of this band in the spectrum of the different stars, suggesting an evolutionary series, has been used to establish the sequence, $+42°$ 2811, $-10°$ 5057, $+5°$ 5223 $+20°$ 5071, $+34°$ 1929, $-10°$ 513, $+61°$ 667, $-3°$ 1685, $+57°$ 702, $+14°$ 2048.

In general the spectrum having the strongest carbon absorption band shows the least light action in the violet. It is interesting at this point to inquire if other changes can be found accompanying the change in this underlying characteristic.

Naturally we expect the color index to indicate this transition. Data are lacking excepting for two stars of the list.

STAR.	COLOR INDEX.
$-10°$ 5057	1.09
$+20$ 5071	1.82

These two follow the proposed order. The visual colors of the 10 stars as recorded in our observational notes appear to be consistent with the sequence. The first one closely resembles the solar type.

Carbon. Accompanying the increase of intensity of the λ 4700 band, a peculiar transformation takes place in the bright region of the spectrum adjoining the head of the band. The absorption line at λ 4743.6 grows much stronger until at the middle of the series it resembles a new head of the band at λ 4745.1. Another line then appears at λ 4751.1, which follows a similar course and at the end of the series appears like a head of the band at λ 4752.8. No explanation is here offered.

In addition to λ 4737 other members of Group IV of the Swan spectrum, λλ 4715, 4697, 4684, are found in the spectra of some of the stars; in other cases, especially late in the sequence, they are not distinguishable on account of the strong absorption in this region. Group V, λλ 4381, 4371, 4365, is weak, if present; lines corresponding only to the second were measured on any of the plates, and they may be identifiable as a chromium line that is widened in sun spots.

Cyanogen Group II, λλ 4606, 4578, 4553, 4532, 4515, 4502, is represented in all of the stars by some of its lines. The intensity of the first of the group varies greatly, but not progressively; λ 4553 appears to grow stronger in the order of the sequence. The first of Cyanogen Group III, 4216, 4197, 4181, is strong; the second is present. In the case of the later stars, the spectrum is weak in this region and consequently the intensity of the lines cannot be compared from star to star. The "chief carbon line q"[17] λ 4268 does not change appreciably in intensity with the sequence, but was not measured in all of the stars.

Chromium. A large number of strong chromium lines appear in the spectra of Class R stars. Many of them are identical with the strong lines of Classes I and II of the electric furnace emission lines investigated by King.[18] We note especially λλ 4254.5, 4275.0, 4289.9, 4337.7, (4339.6-40.3?), 4352.0, 4497.0, 4530.9, 4580.3. No systematic change in intensity can be detected. Some of the strong furnace and arc emission lines, however, are not represented by absorption lines in the stellar spectra.

Vanadium. This element is also represented by numerous lines, the greater number of which are of King's classes I and II. The table of wave-lengths indicates the lines ascribed to Vanadium. No progressive change is noticeable.

Iron. Numerous iron lines are present, chiefly of King's Classes II and III.[19] The most prominent are λλ 4187.9, 4250.6 (blend), 4260.6, 4271.9, 4325.9, 4404.9, 4415.3, 4494.7, 4871.9 (blend), 4920.7. No systematic change is noticeable.

Titanium. The presence of this element is well attested. Several of the lines show a weakening or broadening in the spectra of the later stars. Lines of Classes I, II, and III are most numerous.

Calcium. The line at λ 4227 is strong and broadens, passing along the sequence. The H and K lines appear only on plates of the first star of the sequence.

Nickel. This element is probably present giving λ 4470.7 in some of the stars. It may contribute to λ 4714.6, which does not give accordant values of the wave-length in the series. λ 4866 is very uncertain.

Magnesium. λ 4352.1 may blend with chromium, λ 4351.9, to produce the strong line at λ 4352, which decreases in intensity along the series. λ 4481 is strong, apparently widening in the latter part of the series.

Hydrogen. Hydrogen lines appear on many of the plates, but they are not strong. $H\gamma$ grows poorer in the later stars, where it can scarcely be separated from a strong line at λ 4337.8 attributed to chromium. $H\beta$ appears as a good line with intensity 5 in the spectrum of the first star of the series. It was not measured in the second; it is weak in others, and widens in the later stars of the list.

The displacement of some lines or shift with spectral type determined by Albrecht[20] is indicated in the series of Class R stars. Fifteen of the lines traced through Albrecht's *"Table of Wave-lengths Varying Progressively with Spectral Type"* show a change in the same direction passing along the series of Class R stars to Class N. Since the change in wave-length with spectral type is small, seldom exceeding 0.2 Å from F to K, our test establishes only the direction of the variation, on account of the probable error of ± 0.12 Å in wave-length determination for a single line on a plate.

Plate VIII shows graphically the change in wave-length of λ 4435 with spectral class.

The progressive change in intensity of various lines as we pass along the series has been noted for the different elements. Comparison of these lines and their changes in intensity with a list of lines, whose intensity changes with spectral type[21] from Miss Maury's Class VI to Class XVIII, indicates that, in general, the progressive change in intensity in our series corresponds with the direction given in the Harvard table.

Comparison with solar spectrum. The general resemblance of the spectra of Class R stars to

[17] Crew and Baker; *Ap. J. 16*, 67, 1902.

[18] Lines of Class I are relatively strong at a low temperature (1900°C) and strengthen slowly at higher temperature. Class II lines appear at the low temperature and strengthen rapidly with increase of temperature. *Ap. J. 41*, 1915.

[19] Class III lines are absent or faint at low temperature (1900°C), appear at medium (2200°C) and strengthen rapidly at higher temperature.

[20] *Cordoba Boletin*, No. 1, 1911.

[21] *Harvard Annals*, Vol. 28, p. 60.

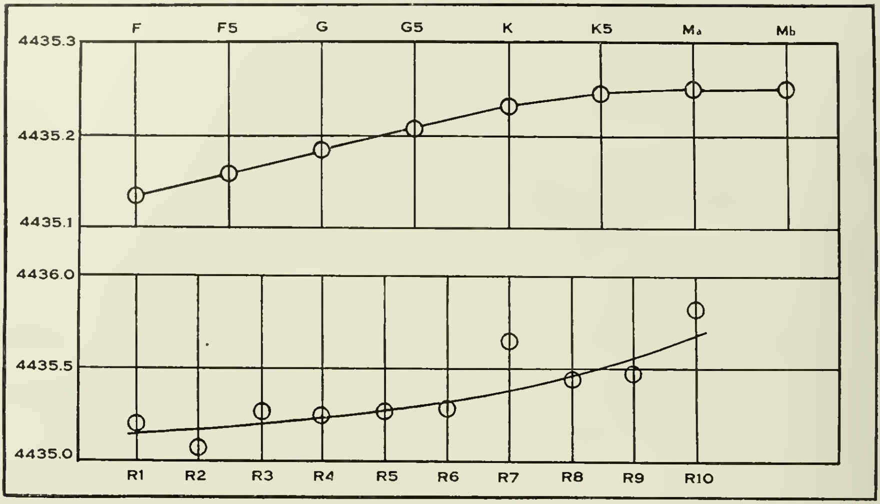

PLATE VIII. CHANGE IN WAVE-LENGTH OF λ4435 WITH SPECTRAL CLASS
OBSERVATIONS OF UPPER CURVE BY ALBRECHT
OBSERVATIONS OF LOWER CURVE BY RUFUS

the solar spectrum with reference to metallic lines harmonizes with the similarity of Types II, III, and IV, pointed out by other writers. Referring to star — 10° 5057, Parkhurst says:[22] "The spectrum resembles the solar type, with the addition of the dark λ 4700 band." He apparently considers that its spectrum differs greatly from the spectra of other stars of Classes N and R, which constituted his list for the determination of color indices, for he places it in a class by itself. We find, however, a very close resemblance between its spectrum and the spectrum of + 42° 2811, one of the recently discovered Class R stars which precedes it in our series. Its spectrum seems to fit well into the sequence adopted on page 136 above. We wish here simply to call attention to the close solar relationship of early Class R stars.

Hale, Ellerman, and Parkhurst have compared fourth type spectra with sun spot spectra and found that a large number of the lines widened in sun spots are strengthened in the spectra of fourth type stars. This result was based upon the region λ 5190 to the red end of the spectrum. From the work of Adams[23] we are able to make a similar comparison for Class R stars from λ 5000 to the violet end.

We have limited our count to the strongest lines of Adams' list, intensity at least 2, because with our slit width and dispersion, many of the faint lines do not appear. About two-thirds of the lines widened in the sun spots appear in Class R stars. Some others may be present, but concealed by the carbon and cyanogen absorption bands. We also note the omission of lines on the less refrangible side of the heads of these bands; e. g. opposite cyanogen λ 4197, the iron lines, λ 4198.2, slightly strengthened in spots; λ 4198.4-.5, a strong blend slightly weakened; λ 4198.8, slightly strengthened and λ 4199.3, strengthened in spots, do not appear on our plates. Also below λ 4447.3 the strengthened lines λ 4447.9 Fe. and λ 4449.3 Ti. are not distinguishable. Among the lines weakened in sun spots, we find many weak or absent in Class R stars. Al-

[22] *Ap. J.* 35, 131, 1912.

[23] *Ap. J.* 27, 45, 1908.

though there is some conflicting evidence the resemblance of the spectra of Class R stars and sun spot spectra seems to be well established.

Comparison with Class O. In the region of the spectrum under consideration, only the following coincidences occur in the bright lines of Classes O and R. The second column gives the number of Class R stars in which the bright line was measured.

CLASS R.	NO.	CLASS O.
λ 4464	4	4465-67
		4473-74
4507	1	4504-10
		4515-18
4538	3	4534-44
		4592-98
4617	1	4614-16
		4650-54
		4862

These coincidences are too few in number to establish any physical relationship. Both classes have bright lines, but this characteristic is shared with other classes.

In addition to the absence of some of the bright lines of Class O stars in the spectra of Class R, many bright lines found in the spectra of Class R stars are lacking in Class O.

There seems to be a shift in wave-length toward the red in the case of λλ 4589-91, 4818-20 and 4896-99, within the series of Class R stars.

The bright lines have not been identified. An explanation for the presence of some, at least, may be sought in the reversal of lines of known elements under certain conditions, rather than by the postulation of unknown elements.

Comparison with Class N. The chief difference between the spectra of stars of Class R and stars of Class N, from the violet end of the spectrum to λ 5000, is in the relative intensity of the spectrum on the two sides of the dark band with head at λ 4737. In general the spectra of stars of Class R extend farther into the violet than the spectra of Class N stars under similar conditions of exposure on stars of comparatively equal photographic magnitude. Ellerman's long exposure on 19 Piscium[24] shows the presence of violet light in this Class N star, giving a spectrum beyond the Fraunhofer H and K lines; and Parkhurst expresses the opinion concerning the spectra of certain stars of Class N, "It is probably a mere question of exposure to extend the other spectra to this region, except perhaps that of 152 Schjellerup." The difference, then, appears to be due to a difference in the quantity rather than in the quality of the violet light emitted by stars of the two classes.

The presence of $H\beta$ as an absorption line in the spectra of many of the Class R stars, and its absence in Class N stars, or presence as a bright line, marks another difference. $H\beta$ has been observed, however, as a bright line in the Class R variables.[25]

The cyanogen bands appear to be somewhat stronger in the spectra of Class N stars, especially λ 4553.6 and λ 4606. An unknown line λ 4443 (Ti spark λ 4444?) appears to be stronger in Class R than in Class N. On some of our plates it is very prominent, having a maximum line intensity of 10, while Hale does not mention it among prominent lines of Class N.

The progressive change in the wave-length of certain lines with spectral type passing from Class R to Class N has already been mentioned as taking place in the direction indicated by Albrecht.

The change in intensity of certain lines with spectral type has also been pointed out. These two features, however, could be better tested by the selection of some later Class N stars,[26] also by the observation of a larger number for wave-length determination.

Another noticeable difference is in the number and intensity of bright lines. The emission lines found in the spectra of Class R stars are in general very weak. In the case of the earlier stars, only a few faint ones were found, any one of which might be considered merely a slight increase in intensity of the continuous spectrum. Later in the series they become more numerous

[24] The Spectra of Stars of Secchi's Fourth Type. *Pub. of Yerkes Ob.*, Vol. II, page 260.

[25] *Harvard Circular*, 76.

[26] We have measured the plates of 19 Piscium, +76° 734, and +34° 4500, all of which are comparatively early Class N stars.

and are stronger, but are not so prominent on the plates of Class R stars as they are on Class N, especially on the plates of U Hydræ, the standard star of Class N.

Concerning the relative strength of carbon absorption in the two classes, we are able to compare the spectra of our series of Class R stars with the series of Class N stars of Hale, Ellerman, and Parkhurst.[27] Since the strength of the λ 4700 band was a determining factor in the arrangement of both sequences the series are practically duplicates. In both Classes R and N, we find stars in which the carbon absorption is relatively weak and others in which parallel degrees of intensity are evident down to the strong bands of $+57°$ 702 (R) and 152 Schjellerup (N). Hale, Ellerman, and Parkhurst placed $+57°$ 702 (R) at the end of their list of stars of type IV. It is evident, therefore, that the strength of carbon absorption is not a distinguishing feature between the two classes, but a factor which enters alike into the spectra of both types. We are thrown back, then, chiefly upon the criterion of general absorption in the violet to differentiate between the spectra of the two classes. This feature appears to be fundamental in the sequence B A F G K M. Although its application is difficult and fails to establish a definite line of demarkation between Classes R and N, the same difficulty is met in the case of other classes. In any natural system of classification, intermediate varieties frequently merge or overlap.

SUMMARY

Relation between Classes R and N. We shall now apply the accumulated data to the first part of our problem, viz., to establish a relationship between Classes N and R. Although the data are meager on some points and may be changed by later investigation, we shall use all in our possession. In Table VIII we tabulate a few results, using the solar type G as a basis of reference.

On all the points it appears that Class R precedes Class N, when the solar type is used as the point of reference.

The close resemblance of the spectra of Classes R and N, and the gradual transition from one to the other with indications of overlapping in the case of the data of individual stars, prove that the two classes are closely related.

These facts indicate clearly that stars belonging to Classes R and N form a continuous sequence with R preceding N.

The place of Classes R and N in the Evolutionary Sequence. We shall now apply our results to the second part of our problem, viz., the relationship between Classes R and N and the sequence B A F G K M. In approaching this problem, two alternatives immediately present themselves: Do the Classes R and N follow M and form one continuous evolutionary sequence, or do they constitute a separate branch of the sequence coordinate with K and M? A more detailed study of the spectra of Classes K and M would be valuable in this connection, but is outside the scope of the present investigation.

Let us first consider some general questions relating to the assumption that spectral type is a linear function, with time as the independent variable. Evidently we are not at liberty to introduce another independent variable, so we must postulate an equal mass of primordial matter for each star, possessing exactly the same properties, and *surrounded by the same conditions.* Then we might expect all the stars to pass through the same evolutionary stages. However, the unequal distribution of stars in space, the presence of nebulous matter in some regions, and the unequal masses of determined systems, indicate that the conditions imposed are imaginary rather than real.

An application of the theory of evolution in other realms of science affords room for the genus to develop into species along diverging branches, possessing common genetic characteristics and different specific characteristics. This type of development may also obtain in stellar evolution.

Hale[28] has summarized the common characteristics of stars of Secchi's types III and IV.[29] 1. Red color. 2. Tendency to variability. 3. Resemblance of dark lines. 4. Presence of lines widened in sun spots. 5. Similar physical con-

[27] *Pub. of Yerkes Obs.*, Vol. II, Plate VIII of *The Spectra of Stars of Secchi's Fourth Type.*

[28] *Pub. of Yerkes Obs.*, Vol. II, 385.

[29] Type III approximately includes Classes K and M; type IV includes R and N.

ditions revealed by spectra. 6. Presence of bright lines. 7. Dark flutings; cyanogen flutings in common. 8. Connection of both types of spectra with spectra of solar stars. We may consider these to be the genetic characteristics.

The chief difference between the spectra of types III and IV is in the special absorption. Type III contains wide absorption bands sharp toward the violet and degraded toward the red, usually attributed to titanium oxide; type IV has similar bands, but reversed in appearance, being sharp toward the red, attributed to some form of carbon compound.[30] This constitutes the specific difference. We have, then, two types of spectra closely resembling each other, with respect to the line spectrum, with a different kind of absorption band superposed. These characteristics meet the conditions for coordinate branches of the evolutionary sequence.

The serious objection against this system of coordination raised by Pechule is that no examples of an intermediate type between the solar spectrum and type IV have been found. The spectra of the earliest stars of Class R seem to refute that objection. The carbon absorption of the first star of our series is comparatively weak, the spectrum extends as far as H and K, and the metallic lines give fair agreement with late solar type. The second star of the series according to Parkhurst has a spectrum resembling the solar type with the bands superposed. In this case the bands are stronger than in the preceding. The faintness of Class R stars and their scarcity lessen the probability of finding better intermediaries. Also, if the difference from the solar type were less, the probability of this difference being detected on a weak plate would be small.

The balanced condition of elements necessary to produce the Swan spectrum (distinguishing feature of Classes R and N) may lessen the probability that many stars exist with carbon bands. Baly[31] calls attention to the fact that the presence of a slight trace of oxygen in the source of light destroys the Swan spectrum due to carbon monoxide and produces the second band spectrum due to carbon dioxide.

However, in spite of these difficulties, as larger instruments are brought into use and the fainter red stars are more thoroughly studied, it is quite probable that examples will be found with weaker carbon bands than the first of the series photographed.

In addition to the qualitative similarity between types III and IV and the close correspondence between the earliest Class R stars and the solar type, we can make a comparison between the Classes R and K. These two classes should correspond quite closely, if the branching takes place following Class G. Perhaps R and K5 are more

TABLE VIII. COMPARISON OF DATA.

	G.	R.	N.
Color Index	1.02	1.7	2.5
In galactic region	58 per cent.	63 per cent.	87 per cent.
Number of variables		8 per cent.	20 per cent.
Residual radial velocity	15.15 km.	14.9 km.	13.2 km. per sec.
Shift in wave-length with type		Slight.	Increased.
Change in intensity of lines		Noted.	Same sense.
Bright lines		Few and weak.	More numerous and stronger.
Hydrogen, Hγ		Weak.	Weaker.
Hydrogen, Hβ		Present, and bright in variables.	Absent or bright.
Calcium, λ 4227	Present.	Widened.	Widened (Hale).
Cyanogen flutings	Absent.	Weak.	Stronger.

[30] Baly thinks the evidence is conclusive in favor of carbon monoxide. *Spectroscopy*, p. 444, 1905.

[31] *Spectroscopy*, p. 444, 1905.

nearly parallel. We shall use data for K5 when available. A comparison follows showing a close correspondence.

	K OR K5	R.
Color index	1.64	1.7
Percentage in galactic region	56	63
Residual radial velocity, G and K	15.15	14.9 km. per sec.
Percentage of variables	Small	8

The correspondence is maintained also by the close similarity of the absorption lines, the shift in wave-length of certain lines with spectral type, the change in intensity of certain lines, absence or weakness of bright lines, weakness of cyanogen flutings, widening of λ 4227, and presence of hydrogen lines.

The close resemblance of the spectra of early Class R stars to the solar type, the parallelism between Classes R and K, together with the fulfillment of the conditions for coordinate branches by the two great classes of red stars (Secchi's types III and IV) lead to the conclusion of the second part of our problem, that the evolutionary sequence is divided, Classes K and M forming one branch and Classes R and N forming the other.

PHYSICAL CONDITIONS

The question arises: What physical conditions differentiate between stars of Classes N and R? Hale has interpreted the physical conditions of fourth type stars. Carbon vapor lies close to the photosphere above which are gases producing the bright lines of the spectra. The thick layer of dense atmosphere produces a strong general absorption. On the basis of this interpretation, the atmosphere of Class R stars is not so thick nor so dense as that of Class N stars and produces less general absorption, permitting the escape of a larger proportion of violet rays, which suffer most from general absorption.

Kapteyn[32] has accumulated much evidence bearing upon the question of the change of spectrum due to the absorption of light in space. Parallax data are not available to determine whether this effect is evident as a differentiating factor between the stars of Classes R and N.

[32] *Ap. J. 40*, 187, 1914.

Another question may arise: How can a solar type evolve two different types of stars? This question suggests another, the burden of proof of which rests with the advocate of the linear evolutionary sequence with R and N following M. How can a star, in which titanium oxide gives the characteristic feature of the spectrum, change into a star in which carbon monoxide predominates? An attempt to answer the first of these two questions seems more probable of success.

Given two stars of solar type under the same conditions, with equal masses, equal volumes, the same constituent elements, and surrounded by the same conditions in space, and the evolution of two different types would appear to be improbable. However, two stars of solar type drifting in different directions, as proper motion indicates, through time and space unlimited, may eventually encounter dissimilar conditions and differentiation may take place.

Moreover, it is quite probable that a differentiation begins before the solar type is reached. Nascent stars will be changed according to the properties of their own constituent elements and the characteristic elements of the matter pervading the surrounding region of space. Both of these factors may vary in different stars. If one region of space or a certain set of conditions is more favorable to the production of carbon and another to the existence of titanium, we may have in different stars of the solar type the right relationship between the various elements for the evolution of two different types of stars, one giving a spectrum in which the carbon bands predominate, the other producing a spectrum characterized by the bands of titanium oxide.

It is a curious fact that we find both elements, carbon and titanium, present in both classes of stars, type III with titanium bands and type IV with carbon bands. The type of spectrum apparently is due to the adjustment between the various elements. Possibly the predominance of carbon vapor in the form of carbon monoxide in the star's atmosphere suppresses the absorbing power of titanium oxide or *vice versa*. The discovery of a stellar spectrum showing the presence of both kinds of bands, carbon and titanium, would be both interesting and instructive. On

account of the delicate balance of elements that would perhaps be necessary to produce such a hybrid, its existence is quite improbable. The delicate adjustment between carbon and oxygen suitable for the production of the Swan spectrum, which has previously been mentioned, may account for the comparatively small number of stars belonging to Classes R and N.

CONCLUSIONS

The radial velocities of ten Class R stars have been determined, with an average probable error $\pm$ 1 km. These radial velocities range from -49 km. to $+25$ km. per second, and yield an average residual radial velocity of 14.9 km. per second.

Wave-lengths of heads of bands, absorption lines and emission lines of Class R stars have been determined, (probable error of the mean in ten plates $\pm$ 0.05 Å) for the region λ 4185 to λ 5000.

The following substances were identified: Carbon (carbon monoxide and cyanogen), hydrogen, chromium, vanadium, titanium, iron, sodium, calcium, magnesium, nickel, and manganese.

Spectrograms of five Class O stars were made for comparison with Class R. No close resemblance was found.

Spectrograms of five Class N stars were obtained, part of which were measured and reduced, for qualitative comparison with Class R stars.

The chief difference between the spectra of stars of Class R and stars of Class N is due to general absorption.

Sixty-three per cent. of Class R stars are in the galactic region ($+30°$ to $-30°$ galactic latitude).

The average color index of five Class R stars (Parkhurst) is 1.7.

The number marked variable in the Harvard tables is 8 per cent.

There is a shift in wave-length and change in intensity of certain lines with spectral type through the R N sequence in the same order as G to M.

Bright lines are not so numerous nor so strong in Class R as in Class N.

Class R precedes Class N in the evolutionary sequence taken in the usual order B A F G K M.

There is a close resemblance between the solar spectrum and the spectra of the first stars of the Class R series.

A marked correspondence exists between Classes R and K in color index, distribution with reference to galaxy, residual radial velocity, tendency to variability, similarity of absorption lines, bright lines, cyanogen flutings, λ 4227, and hydrogen lines.

The evolutionary sequence divides at the solar type, Classes K and M forming one branch, and Classes R and N constituting the other.

Stars of Class R form the connecting links between Class N and the solar type.

The writer wishes to express his grateful acknowledgement to Professor R. H. Curtiss for supervision and direction throughout this investigation, to various members of the Observatory staff for assistance and encouragement, and to those who so kindly arranged the programs of work with the 37½-inch Reflector to make possible the observations on which this study is based.

Ann Arbor, Michigan, June, 1915.

A STUDY OF BETA CEPHEI[1]

By CLIFFORD C. CRUMP

INTRODUCTION

The study of a spectroscopic binary of very short period is of especial interest because of the material it affords for the furtherance of our knowledge of stellar evolution. Through the observation of such a system we are able to derive data with reference to the development of binaries in their early stages and to investigate the laws which govern their evolution. If a star in addition to being a short period binary be a variable of the δ Cephei type the interest is enhanced, for while there are considerable data and many theories concerning Cepheid stars, astronomers agree that a satisfactory solution of the problem of their variation has not been reached and all contributions to the facts already known are particularly valuable.

It is the purpose of this paper to give the results of the study of β Cephei, which is both a short period binary and a variable of the δ Cephei type. The period of β Cephei is the shortest that has thus far been determined for a spectroscopic binary, namely, 4 hours 34 minutes and 17.4 seconds, enabling one to follow it for more than a revolution in a single night. It is remarkable that plates taken with the time of mid-exposure only six minutes apart show a measurable change in the radial velocity of this star. The shortness of the period and the brightness of the star, 3.3 magnitude, make it possible to determine in a comparatively short time the definitive elements of the orbit with the observations grouped around a well defined epoch. It is also possible to compare readily complete cycles of the curve. The recent investigations of the light variation of β Cephei by Guthnick of the Berlin-Babelsberg Observatory have added to the importance of a complete spectroscopic study of this star.

It is proposed to determine definitively the orbital elements of β Cephei and to bring together the existing data concerning it.

[1] A dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

TOTAL LIGHT

As a result of the photoelectric measures of the light variation of β Cephei, Guthnick has announced the star to be a variable. He reaches this conclusion from a series of observations which extend over six months and comprise one hundred and seventy-seven determinations of the light intensity. The light curve plotted from the normal places of his observations indicates an amplitude of 0.05 magnitude as measured with the sodium cell and a range in time from maximum to minimum light of 0.09 days, a little more than one-half the spectroscopic period. The light curve determined by Guthnick compared with the radial velocity curve as observed by Frost showed, on account of the position of the points of maximum and minimum light, that the star was not an Algol nor a β Lyræ variable. The general form of the light curve and the degree of agreement of the point of maximum light with the point of maximum velocity of approach led to the assumption that this variable was of the δ Cephei type. Plate IX, Figure 2, shows the light curve plotted from Guthnick's observations, which may easily be compared with Figure 1 of the same plate, which shows the velocity curve determined at the Detroit Observatory.

According to the general characteristics of Cepheid variables the maximum of light should coincide approximately with the maximum velocity of approach. In most cases this agreement lies within one-fifteenth of the period. Here we observe the difference in time to be 0.029 days, or about one-seventh of the period, a quantity approximately equal to that observed in the case of the Cepheid variable, Y Sagittarii, but with light maximum occurring on the descending branch instead of the ascending branch of the velocity curve. In β Cephei the variation from the general rule of close coincidence between light maximum and maximum velocity of approach may be connected with the closeness of the components of the system. The correspondence between the minimum of light and the mini-

mum velocity of approach in the cases so far observed has not been so close on the average as that between the maximum of light and the maximum velocity of approach. The discrepancy between light minimum and the maximum velocity of recession in the case of β Cephei, though it amounts to about one-fifth of the period, should not exclude it from the δ Cepheid class. This disagreement may be due here and in other cases to variations caused by the ellipsoidal form of the members of the system.

HISTORICAL

From December 18, 1901, to April 16, 1902, six spectrograms of β Cephei ($\alpha = 21^h\ 27^m$, $\delta = +70°\ 7'$) were obtained by Mr. W. S. Adams with the Bruce spectrograph of the Yerkes Observatory. The measures of the third plate of this series suggested a variable radial velocity for this star. This suggestion was confirmed by subsequent investigations of Professor Edwin B. Frost and the binary character of the star was established. An early set of radial velocity determinations showed a range of from — 20.3 km. to + 11.3 km. The period was at first thought to be rather long, but Professor Frost, from two spectrograms taken on the night of May 14, 1902, during an interval of five and one-half hours, observed a change in velocity of 14 km. and inferred that the period was short. Owing to the insufficient data at hand Professor Frost at that time made no attempt to draw further conclusions.

In the spring of 1906 the problem was again taken up by Professor Frost with the idea of determining the period. On the nights of May 18, 19, 20, and 21, eight plates were secured. The approximate measures of these plates indicated that the period was about four hours and thirty minutes. The star was continuously observed through several nights, and from May 28 to August 27 more than sixty plates were made. From the observations of July 6, the following elements were derived:

ELEMENTS OF JULY 6, 1906.

$P = 0.190479$ days,
$e = 0.03 +$,
$\omega = 165°\ 13'$,
$T = 20^h\ 37^m$ G. M. T., or J. D.2417398.859,
$K = 16.9$ km.,
$\gamma = -4.9$ km.

At the meeting of the National Academy of Sciences in December, 1914, Professor Frost gave a brief discussion of this system. In a letter which I have recently received he gives the value of γ on the night of April 29, 1912, as — 10.2 km. The discrepancy between the velocity of the center of mass as given for July 6, 1906, and that determined for this later date is of particular significance and will be discussed in connection with the elements derived by the writer.

OBSERVATIONS

Observations of β Cephei were begun at the Detroit Observatory on August 8, 1912, and were continued until November 21, of that year. During this interval 175 spectrograms were made with the one-prism spectrograph attached to the 37½-inch Reflector. Of the total number of spectrograms obtained 163 were used in the determination of the radial velocities. For the most part Seed 23 plates were used. On the night of October 15 Seed 30 plates were used, with the exception of plates 1247 B, 1249 C, 1250 D, and 1269 B, which were made on Seed 23 plates. The time of exposure varied from five to fifteen minutes. On November 7, conditions being very favorable, thirty-six plates were secured with an average exposure of six minutes. The last series of observations, November 21, was taken with a narrow slit for the purpose of searching the spectrum for double lines. It was the aim from the beginning to follow the star continuously through the period assumed by Frost and on four different nights we were successful in this endeavor.

SPECTRUM

The spectrum of β Cephei is of the Orion type. It is designated in the *Harvard Annals*, Vol. 50, by B1, and in Miss Maury's classification in the *Harvard Annals*, Vol. 28, by IIIa. The chief lines of the spectrum are due to helium, hydrogen, oxygen, and silicon. For a spectrum of this class the lines are well defined and on the whole easy to measure. The series of plates taken with a narrow slit for the purpose of detecting a second component's spectrum gave no evidence that such a spectrum existed. The region used in this investigation extended from λ 3933 to λ 4922. The comparison spectrum was that of the titanium spark.

MEASUREMENT

A part of the spectrograms, namely those of the night of November 21, were measured with Measuring Engine No. 1 of this Observatory, and the remainder of the plates were measured at the Observatorio Nacional de La Plata, Argentina, with a Gærtner engine belonging to the Cordoba Observatory. The screw error of both these engines was so small that correction of the micrometer readings was unnecessary. Twenty-two comparison lines were used on each plate. Three settings were made on the upper comparison line and three on the lower, and the average of these readings was taken as the reading for that line. The average of three settings on the star line was taken as the reading for this line. The correction for curvature of the spectral lines, although small, was taken into account in the reductions. All of the plates were measured direct and reversed in order to eliminate personal equation as far as possible.

WAVE-LENGTHS

Twenty-two star lines were selected for use in the determination of the radial velocities. The wave-lengths were taken from published tables containing such quantities and are incorporated in Table I. Wherever a line was used which could not be identified in some published table the wave-length was computed from the well known Hartmann Formula,

$$\lambda = \lambda_0 + \frac{c}{R_0 - R}.$$

The constants of this formula for the spectrograph used had previously been determined by Mr. Mellor, whose results are published on Volume 1, page 140, of the *Publications of the Detroit Observatory*. The standard of dispersion used by Mr. Mellor having been adopted, the constants determined by him have been used in these reductions.

RADIAL VELOCITIES

The velocities were determined from the measures in the usual manner. Corrections were applied for the orbital velocity of the earth, for the earth's rotation, for the curvature of the lines, and for the small increments which were applied to the wave-lengths of the several star lines to make them homogeneous.

TABLE I. WAVE-LENGTHS OF LINES MEASURED.

ASSUMED WAVE LENGTH.	WAVE-LENGTH IN β CEPHEI.	AUTHORITY.	ELEMENT.
Å	Å		
3933.83	3933.78	Rowland.	K, Calcium.
3964.88	3964.84	Runge and Paschen.	Helium.
3968.62	3968.65	Rowland.	Hϵ, Hydrogen.
3973.48	3973.40	Eisig.	Oxygen.
4009.12	4009.16	Runge and Paschen.	Helium.
4026.37	4026.37	Runge and Paschen.	Helium.
4070.05	4069.94	Crump.	
4072.16	4072.06	Crump.	
4076.08	4076.01	Exner and Haschek.	Oxygen. (?)
4089.00	4089.16	Lunt.	Silicon.
4101.92	4101.92	Curtiss.	Hδ, Hydrogen.
4121.02	4120.92	Runge and Paschen.	Helium.
4143.92	4143.93	Runge and Paschen.	Helium.
4253.81	4254.01	Crump.	
4267.15	4267.22	Eder and Valenta.	Carbon.
4340.63	4340.64	Rowland.	Hγ, Hydrogen.
4388.10	4388.06	Runge and Paschen.	Helium.
4471.68	4471.65	Runge and Paschen.	Helium.
4552.76	4552.82	Albrecht.	Silicon.
4713.31	4713.53	Runge and Paschen.	Helium.
4861.53	4861.56	Rowland.	Hβ, Hydrogen.
4922.10	4922.10	Runge and Paschen.	Helium.

The correction for curvature of the spectral lines, which was obtained on the assumption that the lines were parabolic in form, was made from measures of well defined lines. This correction although small was applied to each determination.

The correction for making the lines homogeneous was made in the following manner. Residuals were found from a comparison of the velocity as given by the line and the velocity as given by the plate. A correction was then applied to each line which would reduce to zero the algebraic sum of the residuals of that line for all of the plates on which it was measured.

The method used in determining the final weights for the lines has been described by Professor Curtiss in his article on δ Orionis, in the *Publications of the Detroit Observatory*, Volume 1, page 123.

Table II contains the observed velocity data. Column 1 gives the number of the plate; column 2, the time of mid-exposure reckoned in days from January 0.0, 1912; column 3, the phase computed with the period determined below, 0.1904795 days, and referred to the epoch of the first observation, 1912, August 23.7576 G.M.T.; column 4, the number of lines measured; column 5, the weight assigned to the plate; column 6, the radial velocity; column 7, the residuals from the final elliptic elements; and column 8, general remarks.

TABLE II. ANN ARBOR OBSERVATIONS.

PLATE NO.	G. M. T. 1912.	PHASE.	NO. OF LINES.	WT.	VELOCITY.	O–C	REMARKS
					km.	km.	
1019 D	236.7576	0.0000	15	13	−21.07	−3.6	
1023 B	239.7847	0.1699	15	11.5	−19.65	+6.2	
1027 B	239.8321	0.0268	17	12.5	−0.33	+3.7	
1028 C	239.8448	0.0395	17	14	−2.50	−2.3	
1029 A	239.8601	0.0548	11	6.5	+2.84	+0.6	
1035 A	240.6979	0.1307	19	15	−27.86	−0.8	
1038 C	242.6437	0.1717	19	22	−23.58	+1.7	
1039 D	242.6528	0.1808	21	31	−27.72	−6.1	
1040 A	242.6618	0.1898	19	25.5	−22.05	−4.6	
1041 B	242.6799	0.0174	18	18.5	−11.55	3.2	
1042 C	242.6896	0.0271	17	10.5	−5.61	−1.9	
1043 D	242.6999	0.0374	17	19	−1.38	−1.3	
1044 A	242.7125	0.0500	17	16.5	−0.52	−2.8	
1045 B	242.7243	0.0618	19	18.5	−2.11	−3.6	
1116 B	275.5646	0.1397	15	26.5	−35.32	−7.5	
1117 C	275.5736	0.1487	17	21.5	−34.73	−5.4	
1118 D	275.5833	0.1584	17	41	−34.23	−5.7	
1119 A	275.5924	0.1675	17	36.5	−29.94	−3.3	
1120 B	275.6000	0.1751	16	29	−25.86	−1.9	
1121 C	275.6090	0.1841	15	23	−16.51	+3.6	Poor.
1122 D	275.6159	0.0005	13	18.5	−16.54	+0.6	
1123 A	275.6250	0.0096	17	21.5	−9.43	+3.0	
1124 B	275.6317	0.0163	12	16.5	−10.77	−1.9	
1125 C	275.6410	0.0256	14	34.5	−3.30	+1.0	
1126 D	275.6486	0.0332	16	31	+3.08	+4.4	
1127 A	275.6562	0.0408	16	23.5	+5.56	+4.7	
1128 B	275.6639	0.0485	20	24	+9.51	+7.4	
1129 C	275.6722	0.0568	18	31.5	+9.00	+7.7	
1130 D	275.6771	0.0617	18	31	+10.13	+8.6	
1131 A	275.6875	0.0721	16	38	−0.43	+0.8	
1132 B	275.6969	0.0815	18	38.5	−8.67	−3.6	
1133 C	275.7049	0.0895	18	27.5	−7.15	+1.8	
1134 D	275.7130	0.0976	15	25	−16.10	−3.0	
1135 A	275.7211	0.1057	17	20.5	−11.69	−5.4	
1136 B	275.7285	0.1131	19	22	−16.35	+4.4	
1137 C	275.7361	0.1207	16	26	−21.34	+2.6	
1138 D	275.7437	0.1283	15	18.5	−27.31	−0.8	
1139 A	275.7521	0.1367	18	25	−32.75	−4.4	
1140 B	275.7604	0.1450	18	26	−28.63	+0.5	
1141 C	275.7705	0.1551	19	23	−23.40	+5.6	

TABLE II. ANN ARBOR OBSERVATIONS—Continued

PLATE NO.	G. M. T. 1912.	PHASE.	NO. OF LINES.	WT.	VELOCITY.	O–C.	REMARKS
1142 D	275.7802	0.1648	18	27.5	−23.56	+3.7	
1247 B	289.5579	0.0375	15	38	+ 5.10	+5.1	
1248 A	289.5642	0.0438	15	22.5	+ 0.55	−0.9	
1249 C	289.5712	0.0508	18	27	+ 0.48	−2.7	
1250 D	289.5802	0.0598	18	35	+ 5.52	+3.8	
1251 A	289.5885	0.0681	14	19	− 2.33	−2.3	
1252 B	289.5962	0.0758	13	14.5	− 2.19	+0.4	Poor.
1253 C	289.6017	0.0813	15	33	− 0.08	+4.9	
1254 D	289.6066	0.0862	14	26.5	− 5.41	+2.0	
1255 A	289.6121	0.0917	16	22.5	− 8.82	+1.3	
1256 B	289.6194	0.0990	17	36.5	−15.41	−1.4	
1257 C	289.6302	0.1098	14	24	−22.06	−2.8	
1258 D	289.6351	0.1147	16	29	−17.73	+3.7	
1259 A	289.6392	0.1188	14	14.5	−23.99	−0.7	
1260 B	289.6434	0.1230	15	22.5	−32.51	−7.7	
1261 C	289.6479	0.1275	11	15.5	−33.48	−7.3	Poor.
1262 D	289.6521	0.1317	15	16.5	−32.22	−4.8	
1263 A	289.6562	0.1358	11	14	−29.19	−0.9	Poor.
1264 B	289.6604	0.1400	11	23.5	−27.23	+1.6	
1265 C	289.6646	0.1442	13	15	−23.30	+6.0	
1266 D	289.6694	0.1490	15	18	−33.49	−4.2	
1267	289.6748	0.1544	12	18	−25.20	+3.8	
1268 A	289.6794	0.1590	13	24	−36.76	−8.4	
1269 B	289.6864	0.1660	19	48	−20.25	+6.8	
1288 A	291.6958	0.0801	15	22.5	− 8.56	−4.0	
1289 B	291.7062	0.0905	19	34.5	− 3.78	+5.8	
1290 C	291.7152	0.0995	15	25	−13.11	+1.0	Poor.
1291 D	291.7243	0.1086	15	12	−11.59	+7.0	Poor.
1292 A	291.7333	0.1174	15	20	−18.28	+4.3	
1293 B	291.7424	0.1267	20	15.5	−28.21	−2.2	Poor.
1294 C	291.7514	0.1357	18	18	−28.73	−0.5	
1295 D	291.7611	0.1454	18	22	−28.66	+0.6	
1296 A	291.7701	0.1544	20	17.5	−20.71	+8.3	
1297 B	291.7792	0.1635	18	18	−29.41	−1.9	
1298 C	291.7882	0.1725	16	18.5	−21.64	+3.5	
1299 D	291.7972	0.1815	16	18.5	−14.42	+7.0	
1304 D	298.6111	0.1381	17	31.5	−29.19	+0.5	
1305 A	298.6229	0.1499	17	24.5	−29.29	+0.0	
1306 B	298.6340	0.1610	17	26	−26.54	+1.5	
1307 C	298.6414	0.1684	18	27.5	−24.41	+1.9	
1308 D	298.6479	0.1749	16	26.5	−21.23	+3.0	
1309 A	298.6555	0.1825	18	25	−23.94	−3.0	
1310 B	298.6590	0.1860	16	15	−16.32	+3.0	Poor.
1311 C	298.6653	0.0019	16	23.5	−10.85	+6.1	
1312 D	298.6705	0.0071	17	29.5	−11.21	+2.5	

TABLE II ANN ARBOR OBSERVATIONS Continued.

PLATE NO.	G. M. T. 1912.	PHASE.	NO. OF LINES.	WT.	VELOCITY.	O−	REMARKS.
					km.	km.	
1313 A	298.6740	0.0112	20	27.5	−10.13	−1.4	
1314 B	298.6790	0.0156	19	22.5	− 2.97	+6.3	
1315 C	298.6830	0.0196	17	26.5	−10.78	−3.5	
1316 D	298.6871	0.0237	17	26.5	− 5.29	+0.1	
1317 B	298.6960	0.0335	18	40	+ 3.34	+4.6	
1318 C	298.7010	0.0370	14	[illegible]	− 4.78	−4.8	
1319 D	298.7052	0.0418	14	21	+ 2.42	+1.4	
1320 A	298.7101	0.0467	16	21	0.69	−1.2	Poor.
1321 B	298.7163	0.0529	18	24.5	0.77	−3.0	
1322 C	298.7212	0.0578	18	27	+ 1.74	−0.2	
1323 D	298.7260	0.0626	19	27.5	+ 4.14	+2.8	
1324 A	298.7302	0.0668	17	35	− 7.15	−7.4	
1325 B	298.7344	0.0710	19	44.5	− 3.13	+2.2	
1326 C	298.7385	0.0751	17	29.5	− 7.19	−4.8	
1327 D	298.7434	0.0800	19	40	− 4.48	−0.0	
1328 A	298.7483	0.0849	19	31.5	−11.03	−4.3	Poor
1330 C	298.7573	0.0939	18	37	− 7.90	+3.3	
1331 D	298.7621	0.0987	19	31.5	−19.19	−5.6	
1332 A	298.7670	0.1036	17	27	− 8.69	+7.6	
1333 B	298.7746	0.1112	20	39	−22.06	−2.0	
1334 C	298.7805	0.1171	20	44.5	−29.30	−6.8	
1335 D	298.7941	0.1307	19	34.5	−30.57	−3.5	
1336 A	298.7983	0.1359	8	17	−24.14	+4.1	Poor.
1337 B	298.8031	0.1397	20	37.5	−27.54	+1.3	
1338 C	298.8073	0.1439	19	42.5	−27.60	+1.6	
1410 C	312.5437	0.1657	15	27	−28.53	−1.5	Poor.
1411 B	312.5528	0.1748	18	27	−24.70	−0.4	
1412 D	312.5576	0.1796	19	34.5	−20.77	+1.5	
1413 A	312.5628	0.1848	20	27.5	−24.82	−4.9	
1414 B	312.5677	0.1897	17	24.5	−19.90	−2.2	
1415 C	312.5727	0.0043	17	28.5	−18.13	0.9	
1416 D	312.5788	0.0104	20	31	−15.81	−3.8	
1417 A	312.5837	0.0153	17	21.5	− 5.34	+4.1	
1418 B	312.5896	0.0212	16	30	−11.42	−4.9	
1419 D	312.5944	0.0260	16	25	− 1.02	+3.2	
1420 D	312.5996	0.0312	17	31	− 4.22	−2.2	
1421 A	312.6045	0.0361	16	23.5	− 2.27	−1.8	Poor.
1422 B	312.6097	0.0413	18	32	+ 4.99	+4.1	
1423 C	312.6146	0.0462	14	18.5	− 1.73	−3.6	
1425 A	312.6246	0.0562	18	34.5	+ 0.69	−1.3	
1426 B	312.6299	0.0615	17	27.5	− 3.63	−5.1	
1427 C	312.6399	0.0715	16	25.5	− 5.58	−4.6	
1428 D	312.6448	0.0764	14	25	− 5.14	−2.3	
1429 A	312.6500	0.0816	16	26	−10.69	−5.6	
1430 B	312.6548	0.0864	13	17.5	−14.22	−6.7	Poor

TABLE II. ANN ARBOR OBSERVATIONS—Continued.

PLATE NO.	G. M. T. 1912.	PHASE.	NO. OF LINES.	WT.	VELOCITY.	O–C.	REMARKS.
					km.	km.	
1431 C	312.6601	0.0917	15	22	−17.22	−7.1	
1432 D	312.6649	0.0965	13	21.5	−14.04	−1.4	
1433 A	312.6701	0.1017	17	25.5	−20.95	−5.8	
1434 B	312.6750	0.1066	15	24.5	−23.18	−5.7	
1435 C	312.6861	0.1177	15	20.5	−24.66	−2.0	
1436 D	312.6920	0.1236	18	25	−28.50	−3.5	
1437 A	312.6976	0.1292	18	21	−25.72	+1.0	
1438 B	312.7028	0.1344	19	25.5	−27.85	−0.2	
1439 C	312.7076	0.1392	19	24	−35.23	−6.5	
1440 D	312.7128	0.1444	16	20.5	−32.45	−3.2	
1441 A	312.7177	0.1493	18	26.5	−31.65	−2.3	
1442 C	312.7229	0.1545	19	34	−27.08	+1.9	
1443 D	312.7277	0.1593	18	26	−22.90	+5.4	
1444 D	312.7337	0.1653	14	19.5	−28.58	−1.5	
1445 B	312.7384	0.1700	7	8.5	−21.07	+5.9	Poor.
1446 C	312.7451	0.1767	11	8	−21.57	+2.0	Poor.
1481 B	326.6246	0.1512	22	34.5	−32.48	−3.2	
1482 C	326.6358	0.1624	21	32.5	−25.87	+1.9	
1483 D	326.6469	0.1735	20	20	−22.54	+2.2	
1484 A	326.6580	0.1846	21	22	−17.48	+2.5	
1485 B	326.6691	0.0052	21	21.5	−18.06	−3.3	
1486 C	326.6802	0.0163	21	21.5	−16.72	−7.6	Poor.
1487 D	326.6913	0.0274	20	38.5	−7.17	−3.6	
1489 A	326.7024	0.0385	19	32.5	−0.05	+0.1	
1490	326.7135	0.0496	17	26.5	−1.84	−4.0	
1491 C	326.7246	0.0607	18	28	+0.09	−1.6	
1492 D	326.7358	0.0719	18	27.5	−0.69	+0.4	
1493 A	326.7469	0.0830	17	25.5	−9.59	−3.8	
1494 B	326.7580	0.0951	18	27	−5.20	+6.8	
1495 C	326.7691	0.1052	17	23.5	−20.69	−3.6	
1496 D	326.7913	0.1274	17	27	−18.14	+8.0	
1497 A	326.8024	0.1385	14	19.5	−25.34	+3.3	
1498 B	326.8184	0.1545	17	28.5	−25.63	+3.4	

PERIOD

The period as determined by Frost was used as the basis for obtaining the period which has been used in this discussion. In obtaining the new period determinations were made of the epochs of the cross-points with the center of mass axis of the velocity curves obtained on the different nights at this Observatory. These values were compared with the epochs for the points as given by the curve drawn by Frost for July 6, 1906. The differences between the corresponding times of these determinations divided by the assumed period gave the number of cycles which had elapsed between these two dates and thereby a means was afforded for the correction of the

assumed period. The following values of the period were obtained by this method.

The mean period of 0.1904795 days was adopted and used throughout this investigation.

PERIOD DETERMINATIONS.

DATE.		PERIOD.
August	29, 1912	0.1904804 days.
October	1, 1912	0.1904792 days.
October	1, 1912	0.1904796 days.
October	24, 1912	0.1904794 days.
October	24, 1912	0.1904792 days.
November	7, 1912	0.1904784 days.
November	7, 1912	0.1904796 days.
November	21, 1912	0.1904799 days.
November	21, 1912	0.1904799 days.
Mean		0.1904795 days.

NORMAL PLACES

The observed radial velocities given in column 6 of Table II were combined into normal places with phase as the basis for grouping. One hundredth of a day was the phase interval over which each normal place extended and accordingly nineteen normal places were formed. The weight for each place was determined on the basis of the sum of the weights of the plates combined to make the normal place. The largest of these sums was taken as unity and the rest reduced to this basis. The phases were reduced to the sun.

The normal places were plotted and a smooth curve was drawn through them. Correction to the normal place velocity for curvature of the curve was then investigated at the maximum and minimum points where such a correction would make itself most manifest. This correction proved to be very small and was not needed outside these regions. Within the limits where it was appreciable it was applied.

The following table gives the data for the normal places.

TABLE III. NORMAL PLACES.

NO.	PHASE.	LIMITS OF PHASE.	VELOCITY.	O–C.	WT.	NO. OF PLATES.
1	0.0056	0.00 to 0.01	−14.48	+0.11	0.522	7
2	0.0166	0.01 to 0.02	−10.07	−1.19	0.616	8
3	0.0269	0.02 to 0.03	− 3.88	+0.08	0.583	7
4	0.0367	0.03 to 0.04	+ 0.38	+0.67	0.808	9
5	0.0464	0.04 to 0.05	+ 2.84	+0.98	0.621	8
6	0.0572	0.05 to 0.06	+ 2.83	+0.71	0.665	8
7	0.0648	0.06 to 0.07	+ 0.01	−0.91	0.612	7
8	0.0748	0.07 to 0.08	− 3.37	−1.17	0.672	7
9	0.0850	0.08 to 0.09	− 7.50	−0.77	0.947	10
10	0.0973	0.09 to 0.10	−11.83	+1.24	0.928	10
11	0.1074	0.10 to 0.11	−17.09	+1.14	0.545	7
12	0.1178	0.11 to 0.12	−22.57	+0.33	0.622	7
13	0.1273	0.12 to 0.13	−26.26	−0.06	0.561	8
14	0.1380	0.13 to 0.14	−30.04	−1.48	1.000	13
15	0.1472	0.14 to 0.15	−29.65	−0.30	0.788	10
16	0.1575	0.15 to 0.16	−28.43	+0.21	0.809	9
17	0.1672	0.16 to 0.17	−25.11	+1.55	0.928	11
18	0.1768	0.17 to 0.18	−22.49	+1.02	0.609	8
19	0.1863	0.18 to 0.19	−21.07	−1.62	0.696	9

LEAST SQUARE SOLUTIONS

A definitive discussion of the orbit requires that the most probable value of ω and of T be found. Both of these values can not be conveniently determined from the least square solution on account of the low eccentricity. From an intensive study of the observations in which different values of ω were assumed and the corresponding values of T computed by the method of least squares the preliminary elements which are given below were adopted for the final least square solution.

PRELIMINARY ELEMENTS.

$$
\begin{aligned}
P &= 0.1904795 \text{ days,}\\
T &= 0^{d}.0543 \text{ Phase, or}\\
&\qquad 1912, \text{ August } 23.8119 \text{ G. M. T.,}\\
e &= 0.044,\\
\omega &= +5^{\circ}.175,\\
K &= 16.125 \text{ km.,}\\
\gamma' &= -13.38 \text{ km.}
\end{aligned}
$$

The method used in the least square solution is essentially that outlined by Dr. Schlesinger in Volume I of the *Allegheny Publications.* Assuming the constancy of the period and the epoch of periastron and employing at Professor Curtiss's suggestion $d\gamma'$, the correction to the mean velocity, instead of Γ as an unknown, the normal equations were formed from which the corrections to the elements were found. The normal equations are as follows:

NORMAL EQUATIONS.

$$
\begin{aligned}
+13.532d\gamma' - 1.083\kappa + 0.207\pi + 5.732\epsilon + 0.177 &= 0,\\
+7.137\kappa + 0.316\pi + 0.122\epsilon + 1.965 &= 0,\\
+6.395\pi + 0.318\epsilon - 4.499 &= 0,\\
+3.808\epsilon - 0.121 &= 0.
\end{aligned}
$$

From these equations the values of the unknown quantities were found to be

$$
\begin{aligned}
\epsilon &= +0.161,\\
\pi &= +0.7157,\\
\kappa &= -0.3277,\\
d\gamma' &= -0.1185.
\end{aligned}
$$

The corrections to the elements were now obtained and applied in the manner indicated. The corrections to the elements are as follows:

$$
\begin{aligned}
\Delta e &= -0.0045,\\
\Delta\omega &= -2^{\circ}.543,\\
\Delta K &= -0.327 \text{ km.,}\\
\Delta\gamma' &= -0.1185 \text{ km.}
\end{aligned}
$$

By adding these corrections to the *Preliminary Elements* we obtain the following

FINAL ELEMENTS.

$$
\begin{aligned}
P &= 0.1904795 \text{ days.}\\
T &= 0^{d}.0543 \text{ Phase, or}\\
&\qquad 1912, \text{ August } 23.8119 \text{ G. M. T.,}\\
e &= 0.040 \pm 0.015,\\
\omega &= +2^{\circ}.632 \pm 0^{\circ}.917,\\
K &= 15.798 \pm 0.24 \text{ km.,}\\
\gamma' &= -13.4985 \pm 0.21 \text{ km.,}\\
a \sin i &= 40.541 \text{ km.,}\\
\gamma &= -14.13 \text{ km.}
\end{aligned}
$$

A second ephemeris was now computed on the basis of the corrected elements and the residuals formed in the usual sense. These residuals were compared with the corrected residuals of the first ephemeris. The resulting differences, the largest of which was $+0.04$ km., showed that a second solution was unnecessary. The sum of the weighted squares of the residuals was reduced from 17.10 to 13.39. The change in this quantity is small, which shows that the observed velocities were well represented by the assumed elements. The probable error of a normal place of weight unity was determined as ± 0.637 km. The probable error of a single plate was ± 2.95 km.

The residuals of the normal place velocities computed from the final elements are found in column 5 of Table III. A glance at these residuals reveals at once an alternation of positive and negative values, suggestive of a secondary oscillation. In Fig. 1 of Plate IX the normal place observed velocities are plotted as small circles, and the velocity curve corresponding to the final elements is drawn as a continuous line. The regular oscillation of the observed velocities above and below the curve corresponding to the final elliptic elements seems well indicated. In this figure the horizontal heavy line represents the mean velocity of the system. The line of long and short dashes oscillating about this horizontal line represents the secondary variation, which when superposed upon the elliptic velocity curve yields the curve of short dashes. This composite curve evidently satisfies the plotted velocities better than the elliptic curve.

At this point the advisability is suggested of a further least square solution containing terms

determinative of the elements of the secondary oscillation. It is hoped that this solution may be made in connection with further studies of this star. For the present in drawing the curves of Fig. 1, Plate IX, after several trials in which the period of the secondary oscillation was taken to be one-third the major period, the semi-amplitude was assumed to be 1.25 km. For the present these values of the elements of the secondary oscillation may be taken as close approximations to definitive values.

OBSERVATIONS OF OCTOBER 1, 1912.

The observations made on the night of October 1, 1912, show a shift of both the points of maximum and minimum from those which were generally observed. The spectrograms secured on this night have been investigated for possible blend effects with negative results. These spectrograms seemed not to be different from those taken on other nights. The lines of the spectrum of the star seemed to be of the same average intensity and the average weight of a plate of this set was in close agreement with the average weight of a plate of a set taken on the night of October 24, which showed no variation from the generally observed results. The Observations of October 1, when plotted, (see Plate X.) seemed to be well satisfied by two straight lines. However, this may have been due to accident and motion in a conic section has been assumed in the reductions.

In order to investigate more thoroughly whether the divergence of the velocities of October 1 from the mean curve was real or due to error in measurement, or to other sources, the data were plotted in Plate X, a set of preliminary elements was computed, and a least square solution was undertaken. The assumed elements, determined by the 45° chordal point method, (see page 178 of this volume,) were as follows:

PRELIMINARY ELEMENTS.

$$
\begin{aligned}
P &= 0.1904795 \text{ days}, \\
\mu &= 1890^\circ.0, \\
T &= 0^d.0628 \text{ Phase}, \\
e &= 0.045, \\
\omega &= +13^\circ.53, \\
K &= 20.31 \text{ km.}, \\
\gamma' &= -11.69.
\end{aligned}
$$

The usual method of procedure was followed, the residuals formed, and the normal equations written as indicated.

NORMAL EQUATIONS.

$$
\begin{aligned}
11.104 d\gamma' - 1.286\kappa - 0.075\pi + 4.200\epsilon + 1.687 &= 0, \\
+ 6.323\kappa + 0.380\pi + 0.014\epsilon - 7.076 &= 0, \\
+ 4.871\pi + 0.165\epsilon + 5.620 &= 0, \\
+ 2.549\epsilon + 1.670 &= 0.
\end{aligned}
$$

From these equations the values of the unknowns were determined as follows:

$$
\begin{aligned}
\epsilon &= -0.308, \\
\pi &= -1.062, \\
\kappa &= -1.088, \\
d\gamma' &= -0.167.
\end{aligned}
$$

and the corresponding corrections to the elements are

$$
\begin{aligned}
\Delta e &= +0.007, \\
\Delta\omega &= +2^\circ.996, \\
\Delta K &= -1.088 \text{ km.}, \\
\Delta\gamma' &= -0.167 \text{ km.}
\end{aligned}
$$

Adding these corrections to the preliminary elements given above we get the

FINAL ELEMENTS FOR OCTOBER 1, 1912.

$$
\begin{aligned}
P &= 0.1904795 \text{ days}, \\
T &= 0^d.0628 \text{ Phase, or} \\
  &\quad 1912, \text{ August } 23.8204 \text{ G. M. T.}, \\
e &= 0.052 \pm 0.058, \\
\omega &= +16^\circ.526 \pm 3^\circ.478, \\
K &= 19.222 \pm 0.711 \text{ km.}, \\
\gamma' &= -11.857 \pm 0.744 \text{ km.}, \\
\gamma &= -12.88 \text{ km.}
\end{aligned}
$$

An ephemeris was computed from these elements and the residuals formed in the usual manner. These quantities compared with the corrected residuals formed from the ephemeris based on the assumed elements showed that a second solution was unnecessary. The sum of the weighted squares of the residuals was reduced from 95.300 to 85.710. The velocity curve corresponding to these final elements is compared with the observations and the *mean curve* in Plate X.

The difference between the value of K from the mean curve and that for October 1, 1912, is considerably greater than the sum of the probable errors of the determinations. The indication is that the difference is not due to accidental error and that the change in amplitude on Octo-

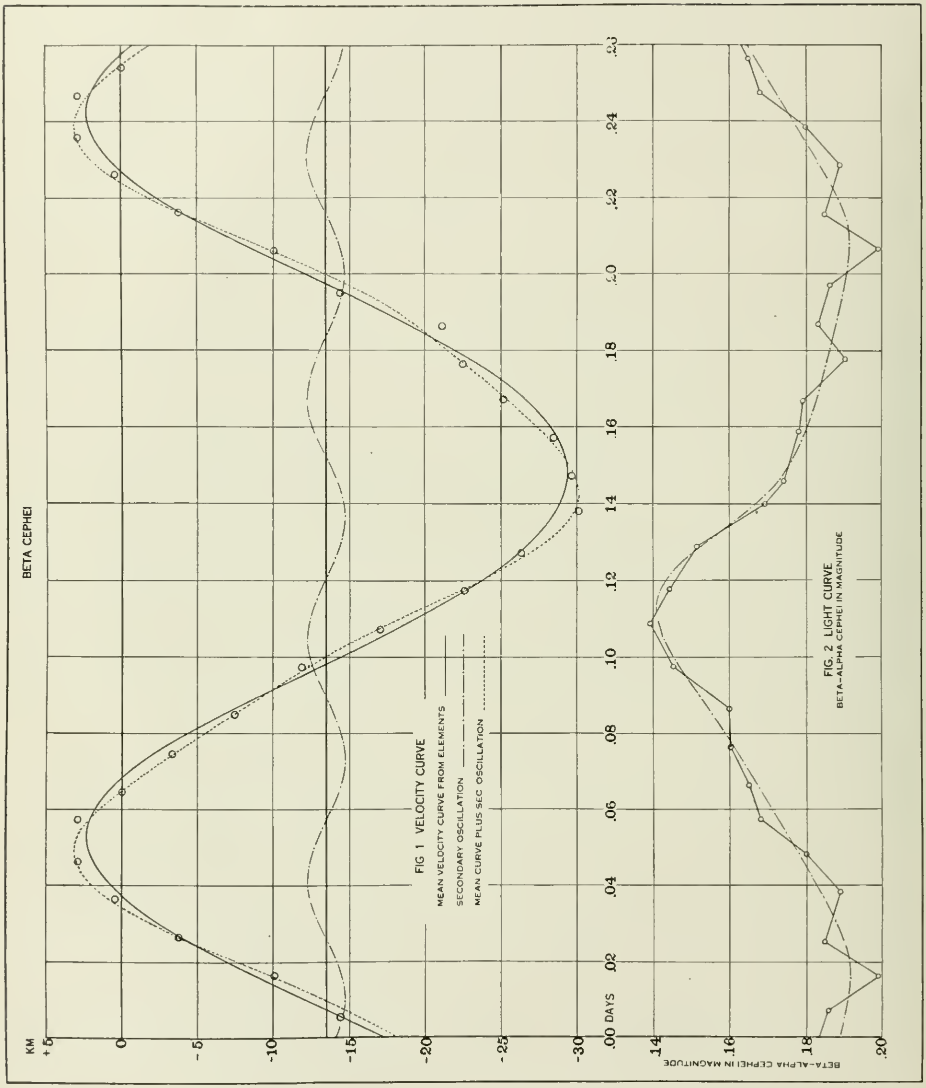

PLATE IX. VELOCITY AND LIGHT CURVES OF β CEPHEI

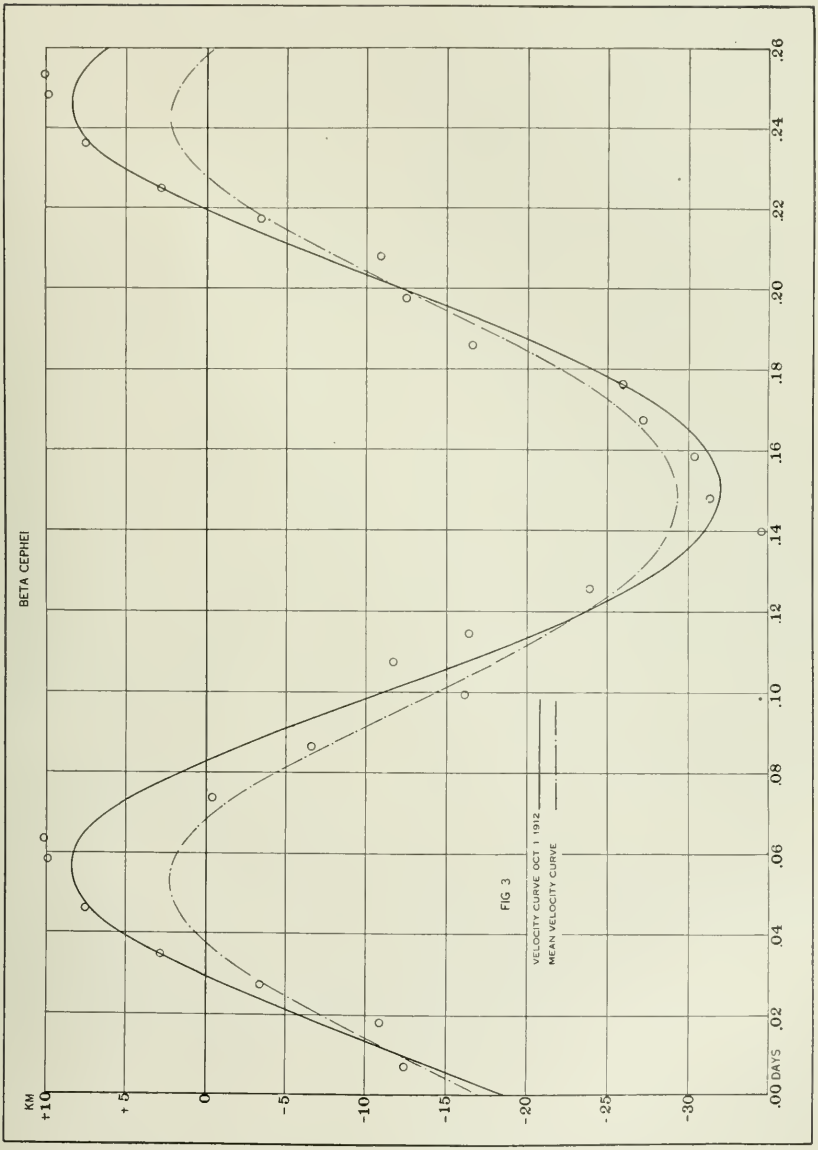

PLATE X. VELOCITY CURVE OF β CEPHEI FOR OCTOBER 1, 1912, COMPARED WITH MEAN CURVE

ber 1 was due to an unknown cause. Further investigation of the nature of this change would undoubtedly be of value.

Variations of the maxima and minima of velocity curves have been observed in the cases of β Orionis by Plaskett and β Coronæ Borealis by Cannon. In the case of β Orionis, Plaskett attributes the change in amplitude to blends or to the perturbations caused by a third body. Cannon found that the shift of the maximum of β Coronæ Borealis was periodic, repeating itself in about twelve periods. In this case he attributes the effect to "a three body system, the body which gives the spectrum measured revolving about another in 40.9 days, and the two, with a third, forming a period of perturbation of 490.8 days."

DISCUSSION OF THE ELEMENTS

Period. The period of β Cephei may be compared with those of the short period variables W Ursæ Majoris, $4^h\ 0^m$, and 14.1904 Cygni, $3^h\ 14^m$, the shortest periods known to the writer. The agreement between the length of the period observed by Frost in the spring of 1906 and that determined at this Observatory in the fall of 1912 is interesting. We can assume the value of $4^h\ 34^m\ 17^s.4$ to be, on the average, the period for the last six years.

Eccentricity. If we apply the probable error in the most favorable way to the value of the eccentricity as given by the definitive elements, we find an agreement of this element with that given by Frost for July 6, 1906.

FROST, 1906.	CRUMP, 1912.
$e = 0.03 +$	$0.04 \pm 0.015.$

These values indicate that the orbit is nearly circular and the agreement shown above would indicate constancy of form.

The Angular Distance from Periastron. A considerable degree of uncertainty pertains to the value of ω. Possibly the large difference between Frost's value of $165°\ 13'$ and that of $2°.63$ determined here is due to the uncertainties connected with the small eccentricity.

The Time of Passage through Ascending Node. The value of T depends upon ω and is therefore difficult to fix in a nearly circular orbit. In this discussion it has been found to be 1912 August 5.8119 G.M.T.

Velocity of the System. The two determinations of the element γ by Frost and that which I made are as follows:

July 6, 1906	$-$ 4.9 km.	Frost.
April 29, 1912	$-$ 10.2 km.	Frost.
August 5, 1912	$-$ 14.13 km.	Crump.

The values indicate a change in the center of mass velocity. A variation of this element has been established in the case of Polaris and suspected by Belopolsky in the case of δ Cephei. In no other cases of Cepheid variables are observations concerning this variation available for study. The change in the velocity of the center of mass may possibly be attributed to the action of a third body.

The Semi-Amplitude. That the half amplitude of the velocity curve K is subject to variation was shown by the variant curve observed on October 1, 1912. During the series of observations this was the only instance of large variation observed. If we compare the value as determined in 1906, of 16.9 km., with the value as obtained at this Observatory in 1912, of 15.8 km., we observe a fair agreement. Though this element may vary from cycle to cycle we do not know whether the average value of this quantity is changing.

SUMMARY AND CONCLUSION

1. As a result of this investigation, definitive elements of the orbit of β Cephei have been determined from 163 velocity observations, whose average probable error determined from an elliptic curve was found to be $\pm$ 2.95 km.

The period of $4^h\ 34^m\ 17^s.4$ is the shortest period which has thus far been observed for a spectroscopic binary. The agreement between the value determined by Frost in 1906, and that determined by the writer in 1912, to the sixth decimal place in days, indicates that on the average the period remained constant during the interval of six years.

The eccentricity of 0.040 shows that the orbit is almost circular. This element is in agreement with the general observation of astrophysicists

that spectroscopic binaries of early type have small eccentricities. It is the smallest eccentricity that has been determined for a variable of the δ Cephei type.

In nearly circular orbits the value of the angular distance of periastron is more or less uncertain. In this case the eccentricity is so small that both ω and T can not be easily determined from a least square solution, and consequently, different values of ω were chosen and the corresponding times of periastron passage computed. The value of this element which seemed the best determined was used with the corresponding value of T in the preliminary elements. Assuming this valve of T as fixed, a final least square solution gave the corrected value of ω as $+ 2$ .63. This determination seems as good as could be expected. The large difference between this value and that of Frost in 1906 may be due to uncertainties affecting its determination.

2. The observations indicate a secondary oscillation whose period appears to be about one-third of the primary. Such an oscillation has been observed by Professor Curtiss in W Sagittarii, and a similar one, though reversed, has been found by Campbell in the case of ζ Geminorum. At present the cause of such oscillations is not known, although Professor Curtiss has suggested a possible explanation in these *Publications*, Vol. I, p. 109. The presence of a secondary oscillation may prove to be a further indication of variation of the δ Cephei type.

3. The velocity curve determined by the writer together with the light curve observed at the Berlin-Babelsberg Observatory confirms Guthnick's conclusion that β Cephei is a variable star of the δ Cephei type. The disagreement observed of about one-seventh of the period between the points of light maximum and maximum velocity of approach is the same as that observed in Y Sagittarii, but occurs on the descending instead of the ascending branch of the velocity curve. This variation may possibly be connected with the closeness of the components of the system. The time interval between the minimum of light and the minimum velocity of approach is observed to be about one-fifth of the period. Although this disagreement is large it would not necessarily exclude it from the δ Cepheid class of variables. In the cases so far observed the agreement between the points of minimum light and minimum velocity of approach has not been so close, on the average, as that between the maximum of light and the maximum velocity of approach. The disagreement may be due to variations caused by the ellipsoidal form of the members of the system, or by other conditions related to the extremely short period.

4. The observations made at this Observatory indicate, as does the unpublished observation of April 29, 1912, kindly communicated to me by Professor Frost, a shift of the center of mass velocity from that determined on July 6, 1906. Only in three cases of Cepheid variables, β Cephei, Polaris, and δ Cephei, are the data available for the determination of the existence of a variation of the velocity of the center of mass. In the first two cases named the variation is present and in the third its presence is suspected. Further observations would be of interest to determine whether this is a characteristic of variables of the δ Cephei type.

5. A variation in the amplitude of the velocity curve was detected and studied. While the amplitude has varied in one case at least we do not know that the average value of this quantity is changing.

It is with pleasure that I acknowledge my indebtedness to Professor R. H. Curtiss for help and supervision throughout this investigation, to Professor G. W. Hess for aid in securing the spectrograms, and to Doctor Laurence Hadley for valuable assistance.

Detroit Observatory, Ann Arbor, Michigan, August, 1915.

THE SPECTRUM AND RADIAL VELOCITY OF RHO LEONIS

By BERNHARD H. DAWSON

Rho Leonis, $\alpha = 10^h 27^m.5$, $\delta = +9° 49'$, was announced as a spectroscopic binary by Campbell in *Lick Observatory Bulletin*, 5, 174 on the basis of six plates by the Lick observers. Although it was later withdrawn from their list, there had been obtained by Harper in the meantime sixty-five spectrograms which had a range of thirty kilometers and thus seemed to confirm the variability of the radial velocity, but without indicating any period.

This star was placed on the observing list at Ann Arbor and forty-three spectrograms were obtained by Curtiss and Mellor on twenty-one nights in 1913 and 1914. These have all been measured by the writer.

THE TOTAL LIGHT

The visual magnitude, as given in the *Harvard Photometry*, is 3.8; and since this star is of early type, the photographic magnitude is probably about 0.2 magnitude brighter. The writer is not aware of its ever having been suspected of variability.

THE SPECTRUM

The spectrum is classed in the *Harvard Annals* as B0p, it being peculiar in having more lines than are usually found in B type spectra. As many as 71 lines have been found measurable on a single plate, and a total of 93 lines have been measured on two or more plates and can thus be considered as certainly in the star. The wave lengths, intensities and a partial identification of these lines, together with other data explained below, as given in Table I. The probable errors in column 5 of this table are based on the agreement of the wave-lengths deduced from the several plates, and do not include the systematic uncertainties (of the order of 0.02 Å) of the corrected interpolation curve.

As noted by Curtiss (these *Publications*, Vol. 1, p. 131) the carbon (?) group at λ 4649.6 appears as a single, rather broad line. The remaining lines of the spectrum are generally sharply defined and easily measurable with this dispersion. On a few plates, notably Nos. 1721, 1804 and 2683, the star lines in the violet, excepting the K line, are considerably broader than in the majority, while the K line and the lines of the comparison spectra remain sharp. This would perhaps indicate that the spectrum was that of a binary with both components bright. But the remarkably sharp definition of the lines in the green and blue of plate No. 1804, and the fact that only in a few sporadic cases has anything like doubling been actually observed would indicate that this was not the true cause, or at least cast considerable doubt on the validity of such a conclusion. In the few cases that a line has appeared double or blended, as often as not values markedly inconsistent with the means of the other lines (which would of course include both components) were obtained by setting on the mean of the pair. Again, if this broadening of the lines be due to relative velocity of two components, they must revolve in a very short period, for against plate No. 1721 we have plate No. 1720, taken less than an hour earlier, in which the lines are sharp, and against plate No. 2683 we have plates both before and after in which the effect is much less marked.

The K line, contrary to Mr. Harper's experience at Ottawa, seems to be at all times well defined on these plates. In those plates in which it was not measured the cause was not poor definition, but the fact that the exposure was insufficient to make anything measurable in that part of the spectrum, for which the (old) prism is rather strongly absorptive. As the measures were made and the reductions begun with the idea that the K line velocity would not agree with that from the other lines, the measures of this line and the few measures of the H line that were made were kept separate throughout the discussion.

None of the plates were sensitized for the visual region.

TABLE I. WAVE-LENGTHS OF LINES IN THE SPECTRUM OF RHO LEONIS.

WAVE-LENGTH.	INT.	NO. OF MEAS.	CLASS.	P. E	SOURCE.	ASSUMED WAVE-LENGTH.	AUTHORITY.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A				A		A	
3889.1	15	3	c	.....	Hζ	....	
3912.3	1	2	c	.....	..	....	
3919.1	1½	2	c	.....	..	....	
3926.8	1½	2	c	.....	..	....	
......	4½	23	.	.....	Ca	3933.825	K, Rowland.
3945.2	1	2	c	.....	..	....	
3954.5	1	3	c	.....	..	....	
3955.8	1½	2	c	.....	..	....	
3964.84	3½	20	b	± 0.022	..	....	
....	2	6	.	.....	Ca	3968.625	H, Rowland.
3970.25	15	7	c	0.009	Hε	....	
3973.51	2½	9	c	0.027	..	....	
3995.13	6	35	b	0.010	..	....	
4009.41	5	25	b	0.020	..	....	
4026.33	12	42	a	0.010	He	4026.37	Runge and Paschen.
4035.23	1	4	c	.....	..	....	
4041.57	1	5	c	0.016	..	....	
4044.3	1	3	c	.....	..	....	
4069.88	2	26	b	0.021	..	....	
4072.37	2	17	b	0.029	..	....	
4076.03	4	33	b	0.018	O	....	
4079.1	1	3	c	.....	..	....	
4081.2	1	2	c	.....	..	....	
4084.6	1	2	c	.....	..	....	
4085.2	1	3	c	.....	..	....	
4086.8	1	2	c	.....	..	....	
4089.21	4½	29	a	0.019	Si	4089.00	Lunt.
4097.22	1	7	c	0.039	Si or N	....	
4101.85	23	42	a	0.011	Hδ	4101.92	
4116.34	1	11	c	0.036	Si	....	
4119.6	½	2	c	.....	..	....	
4120.88	7	16	c	0.028	..	....	
4138.9	1	2	c	.....	..	....	
4143.90	6½	39	b	0.013	..	....	
4153.59	1	7	c	0.041	..	....	
4185.6	1½	3	c	.....	..	....	
4190.02	1½	5	c	0.052	..	....	
4227.90	1	4	c	.....	..	....	
4237.21	1½	7	c	0.044	..	....	
4240.27	2½	19	b	0.021	..	....	
4253.87	2	39	a	0.018	S	4253.77	
4267.34	2½	32	a	0.017	C	4267.15	Eder and Valenta.
4285.16	1½	4	c	.....	..	....	
4304.2	1	2	c	.....	..	....	
4317.37	2	14	b	± 0.040	O	....	

TABLE I. WAVE-LENGTHS OF LINES IN THE SPECTRUM OF RHO LEONIS—CONTINUED.

WAVE-LENGTH.	INT.	NO. OF MEAS.	CLASS.	P. E.	SOURCE.	ASSUMED WAVE-LENGTH.	AUTHORITY.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Å				Å		Å	
4319.89	2	15	b	± 0.036	O	....	
4332.7	½	3	c	.....	..	....	
4337.19	1	4	c	.....	..	....	
4340.62	28	43	a	0.009	Hγ	4340.634	Rowland.
4345.61	2	17	b	0.039	O	....	
4349.61	3	26	b	0.014	O	....	
4351.6	1	2	c	.....	..	....	
4366.95	2½	21	b	0.029	..	....	
4372.1	½	2	c	.....	..	....	
4388.05	8	43	a	0.011	He	4388.10	Runge and Paschen.
4414.91	2½	18	b	0.026	O	....	
4417.20	1½	7	c	0.032	O	....	
4425.2	½	2	c	.....	..	....	
4427.7	½	2	c	.....	..	....	
4437.3	1	2	c	.....	..	....	
4447.27	1½	8	c	0.061	..	....	
4452.6	1	2	c	.....	..	....	
4471.65	13	43	a	0.012	He	4471.68	Runge and Paschen.
4481.23	2	19	b	0.052	Mg	....	
4530.4	1	3	c	.....	..	....	
4552.81	5	43	a	0.010	Si	4552.762	Albrecht.
4567.97	3	41	a	0.011	Si	4567.967	Albrecht.
4574.92	2	37	a	0.023	Si	4574.918	Albrecht.
4587.4	½	2	c	.....	..	....	
4591.21	1½	15	c	0.041	..	....	
4596.62	1¼	10	c	0.055	O	....	
4601.78	1¼	10	c	0.038	..	....	
4607.23	1	7	c	0.053	O	....	
4614.05	1	6	c	0.079	..	....	
4621.48	1	8	c	0.139	..	....	
4626.9	¾	2	c	.....	..	....	
4630.66	2½	34	b	0.019	..	....	
4634.2	½	2	c	.....	..	....	
4638.78	1	8	c	0.043	..	....	
4642.36	2	36	b	0.023	..	....	
4649.64	6	32	a	0.018	C ?	4649.68	Hartmann.
4661.87	2	18	b	0.034	..	....	
4676.22	½	4	c	.....	..	....	
4705.46	½	4	c	.....	..	....	
4713.37	2	34	a	0.018	He	4713.31	Runge and Paschen
4803.7	½	2	c	.....	..	....	
4819.4	½	2	c	.....	..	....	
4838.0	½	2	c	.....	..	....	
4861.47	10	39	a	0.013	Hβ	4861.527	Rowland.
4906.08	½	4	c	.....	..	....	
4911.8	1	3	c	.....	..	....	
4922.11	7½	36	a	± 0.024	He	4922.096	Runge and Paschen.
4946.7	½	2	c	.....	..	....	

FORMER RADIAL VELOCITIES

Six spectrograms of Rho Leonis were obtained by the Lick observers in 1902-1908, and from the discordance of the fifth Campbell announced the variability of the radial velocity in *Lick Observatory Bulletin*, Vol. 5, p. 174. But in a list of errata, (*ib.*, Vol. 6, p. iv.) the values of the velocity from this plate are corrected and the star removed from the list of binaries. As thus corrected, the velocity from this plate is + 41.3 km., using the mean of two measures, while the other plates range from that to + 35.3 km. The mean of all, giving half weight to the fourth, which is published as being somewhat uncertain, is

$$V = +38.8 \pm 0.74 \text{ km.},$$

where the probable error of ± 0.74 km. does not contain the effects of elements systematic to the series.

TABLE Ia. LINES SUSPECTED IN THE SPECTRUM.

WAVE-LENGTH.	PLATE NUMBER.	WAVE-LENGTH.	PLATE NUMBER.
3962.1	1878	4419.6†	1903
3983.5	1878	4422.3†	1903
4032.9	1707	4442.4	2704
4093.1	2681	4581.4†	2704
4111.0	2682	4636.6	2704
4169.4	1707	4665.8	1804
4174.0	1805	4669.8	1804
4176.2	1805	4698.8	1656
4200.2*	1707	4709.6	1804
4233.6	2660	4741.9	1744
4249.6	2660	4774.0	1804
4262.4	1878	4800.3	1804
4295.8	2702	4807.1	1804
4327.4	2695	4813.8	1804
4383.1	1707	4970.0	2687
4410.0	1879	4993.8	2687

* Hδ'. † Perhaps parts of bands.

Harper at Ottawa obtained 65 plates in 1910-1912, and using only eight lines in the determination, deduced radial velocities ranging from + 30 km. to + 52 km., excluding two doubtful plates. After an unsuccessful attempt to find a period to fit the variation indicated he expressed it as his belief that the variation was real, though not definitely established. The measures are published in some detail in *Publications of the Dominion Observatory*, Vol 1, p. 337, where, on the supposition of constant velocity, he derives from them, (page 351), the value:

$$V = +43.2 \pm 3.4 \text{ km.}$$

Using the data of these plates, Schlesinger (*Astrophysical Journal*, Vol. 41, p. 166) deduced a period of 12.28 days, saying that the orbit was probably highly eccentric with periastron near the descending node and an amplitude of the velocity curve of about 20 km. On the basis of this period all the extremely low velocities fall within a day of the phase 7.3 days, the date of Harper's first plate being the zero. The possible range of period for which they all fall within 1.5 days of a single phase is from 12.19 to 12.38 days.

THE ANN ARBOR RADIAL VELOCITIES

The Ann Arbor radial velocities were determined from 43 plates taken with the 37½″ Reflector and single prism spectrograph. All of the plates except No. 1708 are on Seed 23 emulsion with titanium spark comparison. In No. 1708 a Red Label Lantern Slide plate was used by mistake, and the spectrum is consequently considerably underexposed. These plates were all measured by the writer with the engine mentioned on page 80 of Vol. 1 of these *Publications*, according to the customary method here, assigning weights to the various lines on the return measures. All the lines that could be well seen, except the Hε, were generally set on, although only a part of these measures were intended for velocity determination. The K line, and the H line where measured, were kept separate in the reductions. After reduction to mean dispersion fifteen lines were selected, each of which had been measured on nearly all the plates, and for which wave-lengths were at hand. With these lines a preliminary reduction was made, and upon them alone the final mean velocity depends. They are designated by a in column 4 of Table I., and have the originally assumed wave-length and authority given in columns 7 and 8 of the same table. As the star was supposed to be a spectroscopic binary, it was desirable to have better values of the relative velocities from the different

plates, and these lines were accordingly reduced to homogeneity by applying corrections to the wave-lengths such that the weighted mean of the residuals of each individual line was reduced to zero. At the same time these preliminary velocities were used to determine the wave-lengths of eighteen other lines and to make them homogeneous with the first group. These eighteen lines are designated by b in column 4 of Table I. With these 33 homogeneous standards a final reduction was made and velocities obtained which are exhibited in Table II, together with the number of lines used in obtaining each and the probable error deduced from their agreement. These velocities were then used to determine approximate wave-lengths of the remaining lines. The number of lines so determined on each plate is given in column 9 of Table II, and the lines are designated by c in Table I.

In view of the fact that a large number of lines was used and that their character in the spectrum varies considerably from plate to plate it was not thought advisable to go through the process of reweighting them, and the weights assigned to the individual lines at the time of measurement were retained unaltered in the reduction of each plate. But as the measures extended over several months it is not only likely from *a priori* considerations, but also evident from the work itself, that the weight assigned to a line of given value was different in different parts of the series, while still sensibly constant for any one plate. Since the sum of the weights of the individual lines could not be used as the weight of the plate in comparing the various plates, the weighting of the plates became a problem. Assigning values proportional to the inverse squares of the probable errors was seen to give fictitiously high weights to several of the plates with few lines, and to be no more reliable than the sums of the original line weights. It was found that by dividing the number of lines used in velocity determination by the probable error of the plate, quantities were obtained which express very nearly the writer's estimate of the values of the plates from a rapid review of them under the microscope, and this method of weighting was accordingly adopted. The weights thus assigned are given in column 7 of Table II.

The velocities obtained were first plotted on the basis of Schlesinger's period, but showed no sign of variation in any such period. The weighted mean of the plates was accordingly taken, giving:

$$V = +41.1 \pm 0.23 \text{ km.}$$

At the same time the probable error of an average plate was found to be

$$\epsilon = \pm 1.50 \text{ km.},$$

while the probable error deduced from the internal agreement of the lines is

$$\epsilon_1 = \pm 1.23 \text{ km.}$$

Introducing the quantity ϵ_2 used by Curtiss (these *Publications*, Vol. I, p. 134) and defined by the relation

$$\epsilon^2 = \epsilon_1^2 + \epsilon_2^2,$$

we derive the result,

$$\epsilon_2 = \pm 0.86 \text{ km.}$$

Since this value of ϵ_2 is no greater than experience with the spectrograph employed here would lead us to expect for this star in case its velocity were constant the indication is that the Ann Arbor radial velocities contain no evidence of variability.

The fact that the Ottawa observations of this star satisfy a period makes it necessary to limit as above the statement relative to the velocity variability, especially as none of the Ann Arbor observations are at phases exactly corresponding to Schlesinger's minimum, but since there should be some variation indicated in the remainder of the period as well as at minimum, and the Ann Arbor velocities show none, it can at least be said that while the Ann Arbor observations do not supply sufficient evidence for stating definitely that the radial velocity is constant, they nevertheless materially strengthen the evidence in favor of such a conclusion and make the agreement of Harper's low velocities with Schlesinger's period seem more probably fortuitous than the result of any real variation.

THE K LINE

The K line was measured on twenty-three of the forty-three plates, and as before stated, these measures were kept separate. Taking the weighted mean of all, we deduce:

Velocity from the K line $= +1.7 \pm 1.21$ km.

TABLE II. RADIAL VELOCITIES OF RHO LEONIS.

No. of Plate.	Observer.	Date, G. M. T.		General Lines.					K Line.		
				Vel.	No.	P. E.	Wt.	Resid.	No.	Vel.	Wt.
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		1913	d.	km.		km		km.		km.	
1651	Curtiss	April	5.742	+ 40.8	16	± 1.3	12	— 0.3	1	+ 20.1	1
1655	Curtiss		6.636	+ 40.4	23	1.1	20	— 0.7	3	— 3.2	2
1656	Curtiss		6.650	+ 40.3	23	1.3	18	— 0.8	2	+ 9.0	2
1679	Curtiss		13.625	+ 39.8	24	1.1	23	— 1.3	1	0.0	1
1680	Curtiss		13.648	+ 42.1	25	1.4	19	+ 1.0	0	— 6.7	1
1707	Mellor		16.647	+ 40.8	33	0.9	30	— 0.3	29	— 3.0	3
1708	Mellor		16.669	+ 36.2	10	3.9	3	— 4.9	0	....	.
1720	Curtiss		19.588	+ 42.3	27	1.1	24	+ 1.2	1	— 5.7	2
1721	Curtiss		19.620	+ 39.7	26	1.0	26	— 1.4	0	— 5.8	1
1731	Curtiss		20.613	+ 37.7	27	0.9	32	— 3.4	3	+ 5.2	2
1732	Curtiss		20.631	+ 42.2	20	0.6	32	+ 1.1	0	....	.
1743	Mellor		23.622	+ 36.8	25	1.3	19	— 4.3	1	+ 5.3	½
1744	Mellor		23.644	+ 40.6	24	1.2	20	— 0.5	1	....	.
1745	Mellor		23.653	+ 42.2	30	1.0	32	+ 1.1	0	+ 5.3	½
1804	Curtiss	May	1.664	+ 41.9	27	1.3	21	+ 0.8	14	+ 8.0	½
1805	Curtiss		1.680	+ 43.1	25	1.2	20	+ 2.0	8	— 10.8	½
1818	Curtiss		3.608	+ 39.2	28	1.3	22	— 1.9	19	....	.
1819	Curtiss		3.626	+ 40.2	27	1.6	18	— 0.9	6	....	.
1839	Mellor		7.611	+ 44.3	28	1.4	20	+ 3.2	8	....	.
1840	Mellor		7.630	+ 40.7	24	1.1	21	— 0.4	3	....	.
1878	Curtiss		18.598	+ 38.1	33	0.8	43	— 3.0	30	7.5	3
1879	Curtiss		18.616	+ 38.7	30	1.2	25	— 2.4	9	+ 3.8	½
1903	Curtiss		31.628	+ 43.5	23	1.2	20	+ 2.4	6	....	.
1904	Curtiss		31.648	+ 43.2	28	1.3	22	+ 2.1	11	....	.
1960	Curtiss	June	8.599	+ 36.2	18	1.4	13	— 4.9	1	....	.
1961	Curtiss		8.623	+ 41.2	8	2.0	4	0.1	0	....	.
		1914									
2650	Curtiss	March	20.671	+ 41.2	19	1.0	19	+ 0.1	18	— 14.6	1
2663	Curtiss		24.696	+ 44.8	7	1.9	7	+ 3.7	0	....	.
2669	Curtiss	April	5.787	+ 44.9	21	2.1	10	+ 3.8	3	....	.
2672	Curtiss		8.615	+ 44.3	26	1.3	20	+ 3.2	3	— 19.7	½
2673	Curtiss		8.645	+ 42.0	31	1.0	30	+ 0.9	16	— 1.7	1
2681	Curtiss		12.615	+ 43.3	30	1.1	28	+ 2.2	18	+ 3.2	½
2682	Curtiss		12.656	+ 43.2	23	1.5	15	+ 2.1	2	....	.
2683	Curtiss		12.680	+ 44.2	15	0.9	17	+ 3.1	2	+ 12.4	½
2684	Curtiss		12.722	+ 43.8	27	1.4	20	+ 2.7	3	— 4.6	½
2685	Curtiss		12.744	+ 45.0	18	1.3	14	+ 3.9	1	....	.
2686	Curtiss		12.789	+ 43.1	26	1.7	15	+ 2.0	4	....	.
2687	Curtiss		12.827	+ 43.1	21	1.7	13	+ 2.0	2	....	.
2695	Mellor		13.683	+ 41.1	23	1.6	15	0.0	5	+ 8.3	½
2696	Mellor		13.712	+ 38.7	25	1.2	21	— 2.4	5	+ 9.2	½
2702	Mellor		17.634	+ 42.2	16	1.9	8	+ 1.1	2	....	.
2703	Mellor		17.665	+ 36.3	18	2.3	8	— 4.8	2	....	.
2704	Mellor		22.661	+ 39.2	29	± 1.2	24	— 1.9	22	....	.
Means.				+ 41.1 ± 0.23 km.						+ 1.7 ± 1.21	

This result is markedly less positive than that for the other lines and confirms Harper's conclusion with respect to this star. It also agrees in this respect with the results of other observers in cases of other stars of this spectral type. Since in the present case we have the difference occurring at the same time with an apparently constant velocity in the case of each, Hartmann's hypothesis, that the K line is due to a calcium cloud separate from the star and not sharing its velocity, is given added strength.

The width of the Hϵ line was so great that it in most cases obscured the H, which was measurable on only six plates, and which is not discussed. It may be said that the scanty evidence at hand indicates that what is true of the K line applies to the H line as well.

ADDITIONAL LINES SUSPECTED IN THE SPECTRUM

In addition to the 93 lines measured in more than one plate there are several that, although measured in only one, were so definitely indicated on the one where measured that their real existence in the star's spectrum seems probable. Their approximate wave-lengths and the numbers of the plates in which they were measured are given in Table Ia. None of these lines are counted in column 9 of Table II.

CONCLUSION

The results of this investigation may be summed up as follows:

1. The wave-lengths of 91 lines have been determined from measures on two or more plates, and approximate wave-lengths of 32 additional lines probably present in the spectrum have been deduced from single measures.

2. The 43 Ann Arbor radial velocities contain no evidence of variation, and consequently the reality of both the variation deduced from the Ottawa observations by Harper and the period derived by Schlesinger are rendered doubtful.

3. The variations in character of the lines from plate to plate may be taken as evidence of complexity, but the general indications are against such a conclusion.

4. The mean radial velocities deduced are $+1.7 \pm 1.21$ km. for the K line and $+41.1 \pm 0.23$ km. for the others.

5. The K line velocity differs so radically from that of the other lines as to make a common source highly improbable.

I wish to express my thanks to Dr. Curtiss for advice and direction throughout the work.

Ann Arbor, Michigan, June, 1916.

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY DURING THE YEARS 1914 AND 1915

By PAUL W. MERRILL

The record is in the same form as for preceding periods, as given in Volume 1 of these *Publications*, pp. 54-72 and 191-199, except that, commencing with January 1, 1914, all times are given in Greenwich Civil Time, counted from midnight to midnight. The recorded amplitude is the semi-amplitude of the oscillation of the pen. The character * denotes well defined; ÷ gradual.

On December 31, 1914, the magnification of all three components of the Wiechert instruments was changed from 40 to 80. The weight of the horizontal Wiechert was taken apart and readjusted on February 2, 1915. The magnifications and periods of the instruments are now as follows:

	MAGNIFICATION.	PERIOD.
B—EW	40	11.5 sec.
B—NS	50	12.0
W—EW	80	4.9
W—NS	80	6.0
W—V	80	4.2

There is no applied damping.

The distance between the recording pen and the time indicator on each of the Bosch machines is found as follows: Every morning before removing the sheets the pen is swung by a touch of the finger at the exact instant of the minute signal; the distance between this sudden departure from the record line and the preceding minute mark is the "parallax" to be applied to the times read from the sheet.

REMARKS.

110. Another maximum occurred at $4^h 26^m$ with amplitude 0.2 mm. Period at first maximum (M) 30 ± sec., at second maximum 18 sec. Some additional very weak waves a few minutes after F. W—NS shows a trace of S but L is not visible. Bosch instruments were not running at this time.

111. Minutes assumed on W—horizontal records, since hour signals are missing. The main portion consists of very short period vibrations superposed on longer waves. This earthquake was reported by Ottawa observers as "local."

112. A very peculiar disturbance, possibly of artificial origin, (blasting?). Preliminaries very feeble and doubtful.

113. Distance probably accurate. W—NS shows one group of waves $5^h 15^m.0$ to $16^m.3$, amplitude 0.4 mm; another group $5^h 17^m.4$ to $18^m.3$, amplitude 1.0 mm.

114. There are two distinct parts to the main portion: M in the table, records the first maximum; the second maximum occurs about 3.5 min. later.

115. A slow flat shock or groups of slow regular sinusoidal microseisms. B—EW waves from $17^h 37^m.2$÷ to 43^m÷ having a maximum from 40-42^m, amplitude 0.35 mm., period 18 sec., with other smaller groups a few minutes later. B—NS waves from $17^h 32^m.2$÷ to $39^m.2$÷, having a maximum at $32^m.9$; amplitude 0.3 mm., period 19 sec.

W—EW waves from $17^h 32$-33^m; from $37^m.4$÷ to $42^m.7$÷; from 47^m to 49^m. Maximum amplitude 0.15 mm., period 18 sec.

116. Shock apparently in progress when record began. Long waves end at $13^h 56^m$. F is indeterminate, the tail running into irregular microseisms. On W—EW small vibrations began at $13^h 39^m$ or before, stronger motion at $45^m.6$, amplitude 0.5 mm. The W—NS record is weak; the stronger motion began at $44^m.4$.

117. S uncertain; no well marked phases.

118. A very long flat shock. A slight trace on W—V. S possibly misidentified.

119. The Panama earthquake.

120. A long weak shock about 18 hrs.

June 2 Very strong irregular disturbances about 13 hrs. Perhaps artificial.

122. A feeble indefinite shock being somewhat better marked on EW instruments.

123. Horizontal W not running.

NO.	DATE.		INST. COMP.	P	S	L	M	F	A	Δ
	1914			h m	h m	h m	h m	h m	mm.	mgm.
110	Jan.	30	W—EW	.. ....	3 57.9*	4 3†	4 14	4 59	0.1	...
111	Feb.	10	B—EW	.. ....	18 33.9	18 34.6	18 35.1	18 40	1.2	...
			B—NS	.. ....	33.9	34.4	35.1	39	1.3	...
			W—EW	.. ....	33.8	34.5	35.2	40	1.5	Small
			W—NS	.. ....	33.8	34.5	35.1	39	1.0	...
			W—V	.. ....	33.8	34.5	35.1	36.3	0.2	...
112	Feb.	26	B—EW	5 8.5	.. ....	5 16.8	.. ....	.. ....	0.5	...
			B—NS	9.4	.. ....	17.0	.. ....	.. ....	2.9	...
			W—EW	8.3	.. ....	16.8	.. ....	.. ....	1.0	...
			W—NS	8.5	.. ....	16.8	.. ....	.. ....	0.5	...
113	Feb.	28	B—EW	5 8.4	5 12.4	5 15.0	5 16.2	5 29	3.2	...
			B—NS	8.3	12.5	17.4	17.9	34	14.0	2.4
			W—EW	8.3	12.3	15.0	15.7	34	3.9	...
			W—NS	.. ....	Remark					
114	Mar.	30	B—EW	0 47.4	0 52.3	0 58.7?	1 0.4	1 58	6.2	...
			B—NS	0 47.3	52.2	1 1.0	2.4	59	13.3	3.7
			W—EW	.. ....	52.3	0 58.7†	0.1	56	0.7	...
			W—NS	.. ....	52.2	59.7†	2.2	20	1.5	...
115	April	11	B—EW	.. ....	.. ....	17 37.2†	17 41	.. ....	0.35	...
			B—NS	.. ....	.. ....	32.2†	32.9	.. ....	0.2	...
116	April	20	B—EW	.. ....	.. ....	.. ....	13 49.5	.. ....	2.6	...
			B—NS	.. ....	.. ....	.. ....	50.6	.. ....	2.2	...
117	April	24	B—EW	.. ....	8 48.3?	8 51.1	8 51.6	9 1	0.25	...
			B—NS	.. ....	47.5?	48.5	48.7	8 57	0.3	...
			W—EW	.. ....	48.5?	51.3	51.7	58	0.2	...
118	May	26	B—EW	.. ....	14 44.3†	15 28.7	15 32.8	16 43	2.6	...
			B—NS	.. ....	44	29.3	32.5	44	2.0	...
			W—EW	.. ....	44.7†	28.9	32.7	45	0.4	...
			W—NS	.. ....	.. ....	.. ....	32.3	.. ....	0.3	...
119	May	28	B—EW	.. ....	3.35.8*	3 43.4	3 44.5	3 55	0.4	...
			B—NS	3.30.4	.. ....	42.9	44.4	57	0.6	4.
			W—EW	31.6†	35.9*	43.6	44.6	55	0.2	...
120	May	28	B—NS	.. ....	.. ....	.. ....	18 0±	.. ....	...	...
121	May	29	B—EW	.. ....	.. ....	.. ....	6 13	.. ....	...	...
			B—NS	.. ....	.. ....	.. ....	6 13	.. ....	...	...
122	June	20	B—EW	7 { 40.1? / 45.6?	7 49.1?	8 14.7	8 19.9	8 51	0.15	...
			B—NS	.. ....	.. ....	.. ....	29.1	.. ....	0.1	...
			W—EW	{ 40.4? / 45.7?	49.4	13.1	19.6	.. ....	0.1	...
123	June	25	B—EW	19 26.8	19 48.1	20 11.5	20 19.0	21 11	1.0	...
			B—NS	26.2	.. ....	15.0	28.5	5	1.5	...
124	June	26	B—EW	.. ....	.. ....	.. ....	5 49	.. ....	...	...

NO.	DATE.		INST. COMP.	P	S	L	M	F	A	Δ
	1914			h m	h m	h m	h m	h m	mm.	mgm.
125	July	3	B—EW	.. ....	.. ....					
			B—NS	.. ....	.. ....		21 0±	.. ....	...	...
			W—NS	.. ....	.. ....					
126	July	5	B—EW	.. ....	.. ....	3 15.7	.. ....	.. ....	0.15	...
			B—NS	.. ....	.. ....	15.4	3 15.7	.. ....	0.2	...
			W—NS	.. ....	.. ....	15.6	.. ....	.. ....	0.05	...
127	July	5	B—EW	.. ....	.. ....	4 9.7	.. ....	.. ....	0.1	...
			B—NS	.. ....	.. ....	9.8	.. ....	.. ....	0.15	...
			W—NS	.. ....	.. ....	9.9	.. ....	.. ....	0.05	...
128	July	17	B—EW	.. ....	.. ....	7 35.6	7 43.4	.. ....	0.05	...
			B—NS	7 20.8	.. ....	34.8	44	.. ....	0.05	...
129	July	21	B—EW	22 36.8	22 48.4	22 51.1	22 51.5	23 20	2.0	...
			B—NS	35.9	48.2	50.8	51.2	22	1.0	...
			W—EW	.. ....	48.7	51.4	51.8	22 56	0.2	...
			W—NS	.. ....	48.4	51.3	51.4	23 16	0.4	...
130	Aug.	3	B—EW	11 32.0	11 37.7?	11 41.4	11 41.6	11 54	0.3	...
			B—NS	30.9	?	39.4	41.7	.. ....	0.2	3½
			W—EW	.. ....	.. ....	41.5	41.6	43	0.05	...
			W—NS	31.1*	.. ....	40.9	41.8	51	0.1	...
131	Aug.	4	B—EW	23 4.9?	.. ....	23 24†	23 29.7	0 21	1.5	...
			B—NS	5.6*	.. ....	29†	38.7	30	1.5	7?
			W—EW	.. ....	.. ....	28.0	45.7	23 49	0.25	...
			W—NS	5.6	.. ....	29	35.9 43.6	0 29	0.3	...
			W—V	.. ....	.. ....	.. ....	44.7	.. ....	0.1	...
132	Aug.	8	B—EW	19 16.0	.. ....	19 25.1	19 28.4	20 23	2.0	...
			B—NS	. ....	.. ....	25.2	27.3	7	5.6	...
			W—EW	.. ....	.. ....	25.4	26.0	19 39	0.5	...
			W—NS	.. ....	.. ....	25.0	27.3	20 8	0.7	...
133	Aug.	22	B—EW	5 34.8*	5 45.7*	5 48.0	5 48.8	6 32	9.2	...
			B—NS	40.2	45.6†	48.1	48.5	28	8.8	...
			W—EW	37.7	45.7	47.7	48.6	12	0.9	...
			W—V	.. ....	.. ....	48.0	48.6	5 57	0.4	...
134	Aug.	28	B—NS	.. ....	.. ....	.. ....	9 6.0	.. ....	...	...
135	Aug.	28	B—NS	.. ....	.. ....	.. ....	16 4.5	.. ....	0.1	...
136	Aug.	28	B—NS	.. ....	.. ....	17 34	.. ....	.. ....	...	...
137	Sept.	25	B—NS	.. ....	.. ....	.. ....	10 53	.. ....	0.1	...
138	Oct.	3	B—EW	17 30.6*	17 35.9	17 40.9†	17 42.9	18 41	3.9	...
			B—NS	30.7	36.1	40.4?	41	37	3.0	...
			W—EW	30.7	36.0	41.0†	42.6	46	0.7	3.5
			W—NS	30.9	36.0	40.5	41	17 58	0.5	...
			W—V	.. ....	.. ....	40.7	.. ....	.. ....	0.1	...
139	Oct.	22	B—EW	6 57.7	.. ....	7 0.7	7 2.9	7 10	0.2	...
			B—NS	57.7	.. ....	1.3	2.6	6	0.15	...

NO.	DATE.	INST. COMP.	P	S	L	M	F	A	Δ
	1914		h m	h m	h m	h m	h m	mm.	mgm.
140	Oct. 23	B—EW	.. ....	.. ....	.. ....	7 24	.. ....	0.2	...
		B—NS	.. ....	.. ....	.. ....	24	.. ....	0.2	...
141	Nov. 10	B—EW	.. ....	11 22.7	11 25.8?	.. ....	.. ....	0.6	...
		B—NS	11 19.0	23.0	25.8	11 26.1	.. ....	0.5	2.4
		W—EW	.. ....	23.0	?	.. ....	.. ....	0.8	...
142	Nov. 18	B—EW	9 52.1	micros.	?	9 58.9	? micros.	0.8	...
		W—EW	52.2	9 55.9	9 57.3	58.8	10 8	0.4	2.
143	Nov. 24	B—EW	.. ....	12 17.4	.. ....	.. ....	13.21	(2.5)	...
		B—NS	.. ....	17.2	.. ....	.. ....	24	(4.5)	...
		W—EW	.. ....	17.2	.. ....	.. ....	12 55	(1.5)	...
		W—NS	.. ....	17.2	.. ....	.. ....	13 15	(1.1)	...
144	Dec. 4	B—EW	.. ....	22 43.9	22 46.6†	22 46.8	? micros.	0.15	...
		B—NS	.. ....	44.3	46.4	47.2	.. ....	0.1	...
145	Dec. 20	B—EW	.. ....	.. ....	.. ....				
		B—NS	.. ....	.. ....	.. ....	15 0±	.. ....	...	...
		W—NS	.. ....	.. ....	.. ....				
146	Dec. 25	B—EW	.. ....	3 51.4	3 53.8	3 54.3	.. ....	1.3	...
		B—NS	.. ....	54.2	56.7	57.4	.. ....	0.3	...
		W—EW	.. ....	.. ....	.. ....	54.9	.. ....	0.6	...
		W—NS	.. ....	.. ....	.. ....	55.2	.. ....	0.2	...
	1915								
147	Jan. 13	B—EW	.. ....	.. ....	7 28	7 39.6	7 46	0.2	...
		B—NS	.. ....	.. ....	7 24	7 30.3	>8 0	0.5	...
		W—EW	.. ....	.. ....	7 25	7 33	7 44	...	...
148	Mar. 5	B—EW	.. ....	.. ....	4 32.8	.. ....	.. ....	0.7	...
		B—NS	.. ....	.. ....	4 32.9	.. ....	.. ....	0.6	...
		W—EW	.. ....	.. ....	4 32.9	.. ....	.. ....	0.4	...
		W—NS	.. ....	.. ....	4 33.0	.. ....	.. ....	0.4	...
149	April 23	B—EW	15 37.5*	15 43.9*	.. ....	.. ....	16 3+	...	...
		B—NS	15 37.4*	15 44.0*	.. ....	.. ....	16 0+	...	4.8
		W—EW	15 37.5*	15 44.0*	.. ....	.. ....	16 2	...	...
		W—NS	15 37.5*	15 44.0	.. ....	.. ....	? micros.	...	...
150	May 1	B—EW	5 12.0*	5 21.6*	5 43.3	5 43.7	8 6	9.5	...
		B—NS	5 12.1*	5 22.1	5 42.4	5 46.3	7 24	13.6	7.8
		W—EW	5 12.0*	5 21.6	5 43.2	5 43.6	8 6	1.6	...
		W—NS	5 12.0*	5 21.7	5 42†	5 46.3	8 6	3.5	...
151	May 3	B—EW	.. ....	.. ....	.. ....	5 11†	.. ....	...	...
		B—NS	.. ....	.. ....	.. ....	5 11	.. ....	...	...
		W—EW	.. ....	.. ....	.. ....	5 12	.. ....	...	...
		W—NS	.. ....	.. ....	.. ....	5 11+	.. ....	...	...
152	May 6	B—EW	.. ....	12 15.6?	.. ....	12 29.1	13 0±	0.9	...
		B—NS	.. ....	.. ....	12 25.8	12 28.0	13 0±	1.2	7.1?
		W—EW	.. ....	12 15.5?	12 28	12 29.0	13 0+	0.5	...
		W—NS	.. ....	12 15.5?	12 27.7	12 30.5	13 0+	1.8	...

NO.	DATE.		INST. COMP.	P	S	L	M	F	A	Δ
	1915			h m	h m	h m	h m	h m	mm.	mgm.
153	June	1	B—EW	14 59.8?	15 3.3	15 9.7	15 11.0	15 40+	5.4	...
			B—NS	14 53.6?	15 3.3	15 10.3	15 13.5	15 42	3.3	4.9
			W—EW	.. ....	15 2.9	15 9†	15 11.3	15 45	1.4	...
			W—NS	.. ....	.. ....	15 9.0	15 13.5	15 47	1.8	...
154	June	6	B—EW	21 39.7	21 47.8*	.. ....	21 54	22 45+	1.8	...
			B—NS	21 39.6*	21 47.9*	.. ....	22 10	22 35	0.9	6.7
			W—EW	21 39.8	21 48.0*	.. ....	.. ....	23 0±	0.7	...
			W—NS	21 39.8	21.47.9	.. ....	22 10	22 50	0.7	...
155	June	23	B—EW	.. ....†	.. ....	4 14.7	4 15.6	.. ....	1.1	...
			B—NS	.. ....	.. ....	4 12.9	13.7	.. ....	3.0	3.
			W—EW	.. ....	4 12.5?	4 14.7	15.6	.. ....	0.7	...
			W—NS	.. ....	.. ....	4 13.0	14 7	.. ....	2.0	...
156	June	23	B—EW	.. ....†	.. ....	5 11.6	5 12.0	.. ....	1.9	...
			B—NS	.. ....	.. ....	5 9.7	5 11.0	.. ....	2.8	3.
			W—EW	.. ....	5 9. ?	5 11.4	5 11.9	.. ....	0.8	...
			W—NS	.. ....	5 6.1?	5 9.4*	5 10.9	.. ....	2.6	...
157	July	31	B—EW	1 42.6	1 51.8	2 6.6	2 11	3 7	1.6	...
			B—NS	1 42.6	1 51.8	2 6.2	2 13.4	3 8	1.5	8.0
			W—EW	1 42.2	1 51.7	2 6	2 12	3 30	0.5	...
			W—NS	.. ....	.. ....	.. ....	2 13.7	.. ....	0.2	...
			W—V	.. ....	.. ....	.. ....	2 13.7	.. ....	0.1	...
158	Aug.	3	B—EW	.. ....	.. ....	.. ....	14 13	.. ....	...	...
			B—NS	.. ....	.. ....	.. ....	14 13	.. ....	...	...
			W—EW	.. ....	.. ....	.. ....	14 15	.. ....	0.1	...
159	Aug.	7	B—EW	.. ....	.. ....	.. ....	Traces	.. ....	...	...
			B—NS	.. ....	.. ....	.. ....	15 42†	.. ....	...	...
			W—EW	.. ....	.. ....	.. ....	15 49±	.. ....	...	...
160	Sept.	7	B—EW	1 26.8	1 31.7	.. ....	.. ....	3 39	>40	...
			B—NS	1 26.9	1 31.6	1 35.8	.. ....	3 9	>50	...
			W—EW	1 26.9	1.31.6±	.. ....	1 37	3 27	21.4	3
			W—NS	1 26.9	1 31.6±	.. ....	.. ....	3 21	11.6	...
			W—V	.. ....	.. ....	1 36.1	1 39	1 43.3	4.4	...
161	Sept.	7	B—EW	.. ....	.. ....	4 22.0	4 24.0	.. ....	...	...
			B—NS	.. ....	.. ....	.. ....	Trace	.. ....	...	4.?
			W—EW	.. ....	.. ....	4 22	4 23.1	.. ....	...	...
			W—NS	.. ....	4 17.3?	4 21.6	4 26	.. ....	...	...
162	Sept.	7	B—EW	4 33.9†	.. ....	4 45†	4 45.3	5 1	0.4	...
			B—NS	4 34.2?	4 39.8?	4 44.7	4 45.1	4 59	0.4	4.0
			W—EW	4 34.3?	.. ....	4 44.9	4 45.1	4 58	0.1	...
			W—NS	4 34.1	4 39.9?	4 44.6	4 45.0	5 1	0.2	...
163	Sept.	7	B—EW	5 8.8?	5 13.2?	5 18.7	.. ....	.. ....	...	...
			B—NS	.. ....	5 13.8†	5 19.7	5 21	.. ....	0.1—	...
			W—EW	.. ....	5 14.9†	.. ....	Trace	.. ....	...	3.8
			W—NS	5 9.4	5 14.7?	5 19.9	5 20.1	5 30	0.1	...

NO.	DATE.		INST. COMP.	P	S	L	M	F	A	Δ
	1915			h m	h m	h m	h m	h m	mm.	mgm.
164	Sept.	7	B—EW	.. ....	.. ....	.. ....	13 9	.. ....	...	...
			B—NS	.. ....	.. ....	.. ....	13 6–11	.. ....	...	...
			W—EW	.. ....	.. ....	.. ....	13 10	.. ....	...	...
			W—NS	.. ....	.. ....	.. ....	13 9	.. ....	...	...
165	Sept.	7	B—EW	.. ....	20 50.6	.. ....	20 58.3	21 13	0.1	...
			B—NS	20 46.6	20 50.4	20 56.7†	21 1.1	21 14	0.1	4
			W—EW	.. ....	20 52.0?	.. ....	.. ....	21 11	0.1	...
			W—NS	20 45.6?	.. ....	.. ....	21 1	21 12	0.1	...
166	Sept.	12	B—EW	20 50.5?	20 53.1?	21 10±	21 13	.. ....	0.2	...
			B—NS	.. ....	.. ....	.. ....	21 1–4	.. ....	...	...
167	Oct.	2	B—EW	23 52.6	23 55.2?	.. ....	.. ....	.. ....	...	...
			B—NS	23 53.4	.. ....	.. ....	.. ....	.. ....	0.5	...
			W—EW	23 53.4†	23 56.3	.. ....	.. ....	.. ....	0.2	1.8
			W—NS	23 53.5	23 56.9	.. ....	.. ....	.. ....	0.9	...
168	Oct.	3	B—EW	.. ....	.. ....	2 4.6	2 4.9	2 22	0.8	...
			B—NS	.. ....	.. ....	2 3.3?	2 3.5	2 21	0.7	4.5?
			W—EW	.. ....	1 57.8	2 4.3	2 4.6	.. ....	0.3	...
			W—NS	.. ....	.. ....	2 3.6±	2 4.6	.. ....	0.6	...
169	Oct.	3	B—NS	6 59.0	7 3.7	7 5.1	Off sheet	9 0	>67	...
			W—EW	6 59.0	7 3.8±	7 8.?	Double	9 2	28	3.0
			W—NS	6 59.0	7 3.7	7 7.2±	?	9 7	17.0	...
170	Oct.	11	B—EW	19 39.1	19 43.2	19 49.2	19 54.5	.. ....	1.3	...
			B—NS	19 39.3	19 43.5	19 49.5	19 52.1	.. ....	1.0	...
			W—EW	19 39.2	19 43.1?	19 50±	19 53.2	.. ....	0.2	...
			W—NS	19 39.1	19 43.3	19 50±	19 54.1	.. ....	0.3	...
171	Nov.	1	B—EW	.. ....	7 47.5	.. ....	8 23	.. ....	0.8	...
			B—NS	.. ....	7 48	.. ....†	8 22	.. ....	0.8	...
			W—EW	.. ....	7 48	.. ....	8 23	.. ....	0.5	...
			W—NS	.. ....	7 49 ±	.. ....	8 23	.. ....	0.8	...
172	Nov.	21	B—EW	0 23†	0 26.7	0 30.4	0 35	1 35	55.0	...
			B—NS	.. ....	0 27.1	29.8	Off sheet	1 25	>35.0	...
			W—EW	0 23†	0 27.4	31.0	34	1 35	8.5	2.7
			W—NS	.. ....	.. ....	30.7	32	1 10	15.9	...
			W—V	.. ....	.. ....	33.5	32.0	1 36.4	7.8	...
173	Nov.	26	B—EW	.. ....	.. ....	.. ....	Visible	.. ....	...	...
			B—NS	.. ....	.. ....	.. ....†	19 37	.. ....	0.1	...
			W—EW	.. ....	.. ....	19 31	?	.. ....	0.05	...
			W—NS	.. ....	.. ....	.. ....	Trace	.. ....	...	...
174	Dec.	12	B—EW	.. ....	.. ....	21 16.3	21 16.8	.. ....	1.4	...
			W—NS	21 9.1	21 13.6?	.. ....	21 19.3	21 27?	0.1	2.9
175	Dec.	29	B—NS	.. ....	.. ....	0 10.9	0 13.7	.. ....	0.15	...
176	Dec.	31	B—EW	12 26.4	12 31.6	12 39.4	12 39.8	13 16?	3.8	...
			B—NS	.. ....	.. ....†	12 36.4	12 40.0	13 20?	2.4	3.6?
			W—EW	12 26.3	12 31.6	12 39.1	12 39.7	13 19?	0.9	...
			W—NS	.. ....	.. ....	.. ....	12 39.8	.. ....	...	...

126 and 127. The recorded L is the beginning of the disturbance, but later portions, if present, are very weak. However, since the period of the waves is short, 6-7 seconds, in both cases, it is possible that these times should be identified as S in both shocks.

July 13. W—NS shows a slight disturbance at $3^h 17^m$; possibly artificial.

129. Probably one or more phases have been misidentified since the values of Δ from different forms of the Laska formulae are very discordant.

130. The Jamaica earthquake.

131. B—NS record poor.

133. No record of shock on W—NS. Values of Δ discordant.

134. Some microseisms and probably a small shock.

136. Long waves from about $17^h 34^m$ to 18^h. Trace on B—EW.

137. Ecuador earthquake?

138. B—EW shows short vibrations superposed on the first few long waves of the main portion; on W—EW they continue throughout the main portion.

139. A small disturbance, perhaps not a true earthquake. A trace on W—NS; a weaker trace on W—EW; and probably a trace on W—V.

140. Some flat slow waves, period 28 sec., visible on W horizontal.

141. Phases not well marked. Nothing seen on W—NS.

142. On B—NS microseisms are too strong to distinguish earthquake. Very small record on W—NS, the tail being strong, however, and apparently extending to $10^h 16^m$, though this is uncertain on account of microseisms.

143. Curious record: no well marked phases. A refers to initial throw of pen, which is large compared with the disturbances which follow.

146. Small irregular waves superposed on the large ones. Phases very uncertain.

Jan. 6, 1915. Slow flat waves on B—EW having a maximum at 0 hrs., period about 20 sec.

147. Slow flat waves lasting over 20 min. W—NS shows only a very slight trace. Preliminaries are not distinguishable among microseisms.

Feb. 25. A slight disturbance at $9^h 25^m$ in the midst of sinusoidal waves.

Feb. 28. Some flat waves at 20 hrs., period about 20 sec.

148. An irregular disturbance beginning abruptly at times given as L, and lasting a few minutes.

March 28. A small disturbance at $20^h 29^m$ lasting for several minutes in midst of microseisms. Period 10-12 sec

April 7. Some slight disturbances about $16^h 14^m$.

149. If P and S are correctly identified the long waves (L) are not plain being apparently very feeble with short period vibrations superposed. On W—V P is markedly a single sudden small displacement.

April 25. A small disturbance (perhaps artificial) on W—V from $21^h 29^m.8$ to $21^h 30^m.4$. Nothing notable on other records.

150. No appreciable record on W—V.

151. Flat waves, period about 20 sec. Also some very weak waves about one hour earlier.

152. P may be wrongly identified as S.

153. Shock in the midst of slight microseisms on W. W shows short waves superposed on the long ones of the main portion.

154. Amplitudes of S.

B—EW	12.0
B—NS	2.5
W—EW	4.7

June 14. At $22^h 6^m$ there is a small disturbance on W with a trace on B—perhaps artificial.

June 15. W—V shows a small irregular disturbance at $0^h 59^m.6$ probably artificial.

156. In both shocks the long waves die away gradually disappearing in about 15 min.

July 22. B—NS shows a small shock at $4^h 33^m$.

July 25 B—NS and W—EW some very flat slow waves for several minutes beginning $21^h 17\text{-}18^m$. Amplitudes not over 0.1 mm. No well defined maxima.

Aug. 6. Probably some long waves, in the midst of microseisms, about $14^h 6^m$ on W—EW; trace on B—EW; better shown on B—NS; continue feebly for 10-12 min.

Aug. 16. B—EW shows some very feeble waves for 15 minutes, beginning at $1^h 30^m$. Trace on B—NS and W—EW.

Sept. 6. B instruments show a very slight disturbance at $18^h 51^m$.

160. The W pens exhibit a peculiar jerky motion.

164. A very slight disturbance.

165. Phases are very poorly marked and indistinguishable in many cases.

166. Phases poorly marked. Possibly S at $21^h 0^m.7$. Traces on horizontal W. Record poor.

167. B—NS shows a peculiar disturbance beginning at $23^h 53^m 4$ (= P?) visible for about 10 minutes having its maximum at $23^h 55^m.6$. S is doubtful and L very weak if present.

169. B—EW not running. No action on W—V.

170. Phases misidentified?

171. F in microseisms.

Nov. 4. B—NS a few slow waves in the midst of microseisms at $19^h 56^m$, period 18-20 sec., amplitude 0.2 mm.

172. F runs into microseisms. W—NS not very sensitive.

173. Slow flat shock in weak microseisms.

Dec. 7. A peculiar disturbance at $18^h 45^m$ lasting a minute or two, consisting of very short vibrations superposed on longer rather irregular waves. Amplitudes:

B—EW	0.6
B—NS	0.7
W—EW	1.4
W—NS	0.5

174. B—NS trace but microseisms too strong. W—EW out or order.

Dec. 17. B—NS shows a few slow flat waves with M at $8^h 5^m$.

175. B—EW microseisms mask. W—EW pen behaves badly.

176. W—NS insensitive. Time of L not accurate?

MICROSEISMS, 1914 AND 1915

1914.

Jan. 1-9.
Sinusoidal microseisms coming to a maximum on 3-4^d. Best shown on EW components where they have a maximum amplitude of 0.2 mm. and a period of 5-6 seconds.

Jan. 9-11.
Waves slower and more irregular.

Jan. 11-12.
Tremors stronger.

INST.—COMP.	MAX. AMPLITUDE.	PERIOD.
	mm.	sec.
B—EW	0.25	5-6½
B—NS	0.3	5-6
W—EW	0.1	6
W—NS	?	...

Jan. 12-13.
Same. Period 5 seconds.

Jan. 13-15.
Weaker.

Jan. 16-18.
Tremors faint.

Jan. 18-19.
Stronger.

Jan. 19-20.
Considerably stronger.

INST.—COMP.	MAX. AMPLITUDE.	PERIOD.
	mm.	sec.
B—EW	0.4	6
B—NS	0.3	6
W—EW	0.1	6
W—NS	Very small.	

Jan. 20-21.
Tremors continue. Some well marked groups.

Jan. 21-23.
Weaker.

Jan. 23-24.
A few small tremors. Nearly continuous on B—EW.

Jan. 24-25.
Some slow irregular waves.

Jan. 25-26.
Weak, regular, sinusoidal waves, with occasional stronger groups on W—EW. Period 4 sec.

Jan. 26-29.
Tremors die away gradually.

Jan. 31-Feb. 5.
Slight irregular tremors.

Feb. 5-9.
Growing stronger, particularly on EW instruments where they are perfectly continuous on 7-9.

Feb. 9-11.
Tremors grow weaker.

Feb. 11-13.
Irregular tremors stronger, particularly toward last of 12-13[d], being then very irregular and peculiar. Stronger on NS than before.

Feb. 13-14.
Much weaker, dying down during the day.

Feb. 14-15.
Weak tremors visible. Some regular sinusoidal waves.

Feb. 15-17.
Same, weaker.

Feb. 17-18.
Irregular tremors extremely feeble. Some regular sinusoidal waves on B—NS and more faintly on B—EW. Period about 6 seconds.

Feb. 18-19.
Slightly stronger. Visible on W—EW.

Feb. 19-20.
Weaker.

Feb. 20-21.
Regular sinusoidal waves in groups but usually connected by small tremors. Amplitude small, about 0.1 mm. Period about 6 seconds.

Feb. 21-25.
Weak sinusoidal waves which are more prominent on EW components.

Feb. 26-27.
Numerous small sinusoidal waves on all horizontal instruments.

March 1-3.
Regular sinusoidal waves nearly continuous. Best shown on NS records.

INST.—COMP.	MAX. AMPLITUDE.	PERIOD.
	mm.	sec.
B—NS	0.2	5
W—NS	0.05	5

March 3-5.
Traces of above.

March 9-15.
Very slight tremors, some being irregular.

March 16-20.
Irregular tremors, stronger during first part of day.

March 20-23.
Some feeble regular sinusoidal microseisms.

March 25-26.
Irregular tremors; stronger during the day than at night.

March 31-April 1.
Some slight regular sinusoidal waves on NS records.

April 1-2.
Same; stronger.

April 2-3.
Microseisms weaker and somewhat irregular.

April 4-5.
Some slow irregularities on NS records.

April 7-8.
Slight irregular motion toward latter part of record on B—NS.

April 8-12.
Same; visible also on B—EW.

April 19-20.
Fairly strong irregular microseisms on B—NS.

April 20-21.
Same; weaker.

April 24-25.
Many regular sinusoidal waves. period about $5\frac{1}{2}$ sec.

April 25-26.
Some feeble tremors, slightly slower.

April 29-30.
Slight irregular tremors on B—EW.

May 13-14.
B—NS very slight irregular tremors, stronger toward morning of 14th.

May 22-23.
B—NS some slight microseisms.

May 29-30.
B—NS some slight microseisms occasionally.

June 5-6.
B—NS some very slight slow irregular tremors.

June 10-11.
B—NS very slight tremors.

June 13-16.
Same.

June 18-19.
Same.

June 29-July 2.
B—NS a few weak tremors.

July 7-10.
B—NS numerous very small tremors decrease in strength to 10th.

July 11-12.
B—NS some very small temors of short period.

July 13-16.
Minute slow tremors.

July 16-18.
Small tremors on B—NS.

July 24-25.
Some faint tremors on B—NS. It is not certain whether they continue after this day since the records of this instrument are poor during the next few days.

Aug. 11-12.
B—NS weak tremors.

Aug. 12-14.
Stronger; seen also on B—EW.

Aug. 14-16.
Weaker.

Aug. 17-18.
Some small tremors.

Aug. 25-27.
B—NS shows small tremors which are nearly continuous on 26-27.

Aug. 27-28.
Weaker.

Sept. 2-4.
Slight sinusoidal waves on B instruments.

Sept. 4-5.
Very slight tremors.

Sept. 5-6.
Stronger. ?

Sept. 6-8.
Stronger, particularly on EW. Trace on W.

Sept. 8-11.
Tremors die away gradually.

Sept. 15-26.
Weak regular sinusoidal waves; strongest on 17-18.

Sept. 26-27.
Very regular sinusoidal waves practically continuous.

Sept. 27-29.
Stronger. Traces on W.

Sept. 29-30.
Much weaker.

Sept. 30-Oct. 3.
Small sinusoidal waves.

Oct. 3-4.
Microseisms present but weaker.

Oct. 4-7.
Slight sinusoidal waves.

Oct. 11-12.
B—NS slow flat microseisms?

Oct. 12-13.
Slight regular sinusoidal waves.

Oct. 13-14.
Apparently some slight slow irregular oscillations on B—NS, but B—EW shows only regular sinusoidal waves.

Oct. 14-15.
Very weak regular sinusoidal waves.

Oct. 15-16.
The motion very feeble.

Oct. 16-21.
Rather strong sinusoidal pulsations on 16-17, and 18-19; die away slowly.

Oct. 23-28.
Sinusoidal.

Oct. 28-30.
Much stronger.

Oct. 30-31.
Not so strong.

Oct. 31-Nov. 8.
Sinusoidal, strongest on 1-3.

Nov. 8-9.
Numerous groups of sinusoidal waves,—trains?

Nov. 9-10.
Irregular tremors.

Nov. 10-11.
Same. Small sinusoidal waves on B—EW.

Nov. 11-12.
Regular sinusoidal waves, stronger.

Nov. 12-13.
Weaker, dying away.

Nov. 13.
B—NS irregular waves in the morning.

Nov. 15-16.
B—NS irregular waves stronger toward end of record. Very much smaller ones on B—EW.

Nov. 16-18.
Very strong irregular waves on B—NS; smaller ones on B—EW.

Nov. 18-24.
Microseisms, stronger on 20-21.

Nov. 24-25.
Slight irregular tremors.

Dec. 2-7.
B—NS irregular microseisms, slightly stronger on 5-6.

Dec. 7-30.
Numerous microseisms every day.

Dec. 13-14.
Microseisms become considerably stronger during latter part of record.

Dec. 14-15.
B—NS very strong irregular tremors all day. Weaker and more regular on B—EW. Scarcely visible on W.

Dec. 15-21.
Above die down to weak tremors.

Dec. 21-22.
Tremors stronger on latter portion of B records.

Dec. 22-23.
Continued throughout record.

Dec. 23-25.
Weaker.

Dec. 25-27.
Tremors grow stronger.

Dec. 27-30.
Grow weaker.

1915

Dec. 31-Jan. 3.
Rather strong irregular microseisms, being weaker on 2-3.

Jan. 3-4.
Microseisms stronger and more regular.

Jan. 4-5.
Same; a few large slow irregular motions in first part of day.

Jan. 5-6.
Microseisms weaker.

Jan. 6-8.
Irregular tremors increase and die away.

Jan. 8-11.
Small tremors stronger on 10-11.

Jan. 11-13.
Sinusoidal waves in groups; better marked on EW.

Jan. 13-14.
All records, including W—V exhibit very striking sinusoidal waves, showing the group structure. The period on all instruments is about 5½ seconds.

Jan. 14-16.
Fade away.

Jan. 17-23.
Small microseisms, partly of sinusoidal nature on B—EW, more irregular on B—NS.

Jan. 23-24.
Tremors stronger, continuous B—NS.

Jan. 24-25.
W—EW some short sinusoidal waves, period 3-4 seconds.

Jan. 28-31.
Tremors as before, being more regular on EW.

Jan. 31-Feb. 1.
A few weak tremors.

Feb. 1-2.
Stronger toward latter part of day, sinusoidal.

Feb. 2-10.
Continue.

Feb. 14-17.
Few weak and slow tremors.

Feb. 17-18.
Slight quick sinusoidal waves, 15-20 per minute.

Feb. 18-20.
Grow less.

Feb. 24-25.
Some small sinusoidal waves.

Feb. 25-28.
Fairly strong irregular tremors, especially on EW; grow weaker.

Mar. 1-2.
Slight disturbances throughout day.

Mar. 3-5.
Slight microseisms.

Mar. 6-7.
Slight tremors.

Mar. 10-11.
Die down but become considerably stronger toward latter part of record.

Mar. 11-12.
Marked sinusoidal waves with strong groups.

Mar. 12-17.
Decrease in intensity.

Mar. 17-19.
Stronger and more continuous.

Mar. 19-24.
Decrease.

Mar. 24-25.
Somewhat stronger.

Mar. 25-31.
Tremors much weaker at end of the period.

Mar. 31-Apr. 1.
Faint tremors most pronounced on W—NS where they appear as groups of sinusoidal waves.

Apr. 1-2.
Weaker.

Apr. 2-4.
Increase.

Apr. 4-8.
Die away.

Apr. 8-10.
Sinusoidal waves stronger again, especially on W.

Apr. 10-11.
Much weaker and in detached groups.

Apr. 11-12.
Slow irregular disturbances throughout day on B—NS; occasional groups of sinusoidal waves on W. Trains?

Apr. 12-17.
Microseisms, being strongest on 14-15.

Apr. 18-19.
Microseisms, more prominent on W.

Apr. 21-23.
Sinusoidal waves, stronger on 21-22.

Apr. 25-26.
Some sinusoidal waves.

Apr. 29-30.
Some irregular disturbances on B—NS.

May 6-7.
Traces of microseisms on W.

May 7-8.
Some sinusoidal waves, in groups.

May 14-15.
Some feeble sinusoidal waves.

May 27-31.
Same.

June.
First few days of month slight traces of sinusoidal waves almost continually on both components of EW, accentuated by trains.

July 1-2.
Some very slight sinusoidal waves.

July 6-7.
Slight and rather irregular microseisms.

July 15-16.
Slight microseisms.

July 20-21.
Slight sinusoidal waves.

July 23-24.
Occasional sinusoidal waves on W—EW.

July 26-27.
Sinusoidal waves on early part of W—EW record.

Aug. 5-6.
Microseisms, stronger toward end of record

Aug. 16-18.
Some very slight tremors on EW.

Aug. 18-20.
Stronger.

Aug. 20-22.
Die away.

Aug. 23-25.
Tremors as above.

Aug. 26-29.
Feeble tremors.

Sept. 1-5.
Slight sinusoidal waves, strongest on 3-4.

Sept. 8-9.
Slight traces of microseisms.

Sept. 13.
Weak microseisms, nearly continuous throughout remainder of the month, being stronger on Sept. 23-24, 27-29, and weak on Sept. 18-19, 25-27, 29-30.

Sept. 30-Oct. 2.
Slight microseisms.

Oct. 6-8.
Microseisms increase and wane.

Oct. 8-10.
Microseisms just visible.

Oct. 10-14.
Weak microseisms.

Oct. 15-22.
Very feeble microseisms.

Oct. 22-24.
Much stronger sinusoidal waves.

Oct. 24-27.
Weaker.

Oct. 27-28.
Practically disappear.

Oct. 28-29.
Some slight rather irregular motion.

Oct. 31-Nov. 1.
Fairly strong irregular microseisms all day, with an earthquake superposed on them.

Nov. 1-2.
Fairly strong sinusoidal microseisms.

Nov. 2-4.
Continue, weaker.

Nov. 4-5.
Slightly stronger.

Nov. 5-7.
Much less prominent.

Nov. 7-9.
Somewhat stronger.

Nov. 9-11.
Feeble.

Nov. 11-13.
Somewhat stronger.

Nov. 13-14.
Weaker, not continuous.

Nov. 14-16.
Grow considerably stronger.

Nov. 16-17.
Slightly less.

Nov. 17-20.
Sinusoidal microseisms. Principally in groups.

Nov. 20-22.
Nearly continuous, rather irregular.

Nov. 22-26.
Grow weaker.

Nov. 28-29.
Irregular. Grow quite strong toward end of record, especially on B—NS.

Nov. 29-30.
Slow microseisms, with occasional groups of stronger waves. Best shown on B—NS.

Nov. 30-Dec. 1.
Microseisms visible.

Dec. 1-4.
More sinusoidal in character.

Dec. 4-10.
Weak microseisms.

Dec. 10-13.
Strong sinusoidal microseisms, slacking toward end.

Dec. 13-15.
Weaker but still conspicuous on B, especially B—NS.

Dec. 15-19.
Weaker.

Dec. 19-21.
Rather slow and irregular.

Dec. 21-24.
Sinusoidal microseisms, with emphasized groups.

Dec. 24-25.
Practically no microseisms.

Dec. 25-26.
Feeble microseisms toward end of record.

Dec. 26-27.
Sinusoidal microseisms mostly in groups.

Dec. 27-31.
Sinusoidal waves stronger.

OBSERVATORY NOTES

ON A METHOD ADOPTED FOR THE DETERMINATION OF THE ELEMENTS OF SPECTROSCOPIC BINARIES WITH AN ABBREVIATION OF THE LEAST-SQUARES SOLUTION

By RALPH H. CURTISS

For several years the writer has presented in a course on spectroscopic binary orbits the various formulæ which have been proposed for the determination of the elements of these stellar systems from measures of radial velocity. In connection with this course all the geometrical methods, beginning with that of Lehmann-Filhés, have been tested and compared many times. Taking these tests and comparisons into account, a method has been adopted at this Observatory, which is short, determinate, and quite satisfactory in practice. The formulæ, which are obtained easily from those derived by H. C. Plummer on pages 214 and 215 of Volume 28 of the *Astrophysical Journal*, are given below.

In addition to the symbols more frequently employed in this connection, we define:

γ', the algebraic mean of the maximum and minimum ordinates of the velocity curve, referred to the zero axis.

t_1, t_3, t_2, t_4, the abscissae of the points of the velocity curve corresponding to the ends of chords of the orbit making angles of 45° with the line of apsides, (The ordinates of these points, beginning on the descending branch of the velocity curve are $\gamma' + 0.7071\,K$, $\gamma' - 0.7071\,K$, $\gamma' - 0.7071\,K$, and $\gamma' + 0.7071\,K$ respectively.)

η, the quantity, $\frac{1}{2}(E_2 - E_1)$,
η', the quantity, $\frac{1}{2}(E_4 - E_3)$.

τ, the quantity, $\dfrac{t_2 - t_1}{P}$,

τ', the quantity, $\dfrac{t_4 - t_3}{P}$,

The formulae are:

$$2\pi\tau = 2\eta - \sin 2\eta, \tag{1}$$

$$2\pi\tau' = 2\eta' - \sin 2\eta', \tag{2}$$

$$\tan(45^\circ - \omega) = +\frac{\cot\eta}{\cot\eta'}, \tag{3}$$

$$\tan\phi = -\frac{\cot\eta}{\sin(45^\circ - \omega)} = -\frac{\cot\eta'}{\cos(45^\circ - \omega)} \tag{4}$$

$$v_1 = 45^\circ - \omega, \tag{5}$$

$$v_3 = 90^\circ + v_1, \tag{6}$$

$$T = t_1 - M_1/\mu = t_3 - M_3/\mu. \tag{7}$$

In applying this method the quantities, $\gamma' \pm 0.7071\,K$, are first computed and the corresponding abscissæ are read off the preliminary curve. The values of τ and τ' are formed and equations (1) and (2) are then solved by Table I below. ω and e follow from equations (3) and (4) and may be checked roughly by Tables II and III. v_1 and v_3 may then be written down from relations (5) and (6). M_1 and M_3, corresponding to v_1 and v_3, are taken from the *Tables for the True Anomaly*, given in the *Publications of the Allegheny Observatory*, Vol. 2, No. 17. Two values of T follow from formula (7), and a third more briefly by noting the value of t whose ordinate is $\gamma' + K\cos\omega$. The differences among these values will give some indication of the departure from ellipticity of the preliminary curve. The adopted value of T may be a straight mean of these values or a compromise suggested by a consideration of the conditions of the case.

An ephemeris is then computed at convenient intervals with the formula,

$$V = \gamma' + K\cos u,$$

using again the *Tables for the True Anomaly*, referred to above, to proceed from M to v. With the curve given by this ephemeris as a guide, it is a few minutes work to make a second, and usually final, determination of the elements if the first set is not satisfactory.

To facilitate the use of this method Table I is published below. This table contains values of η (or η') tabulated with τ (or τ') as argument and also first differences of the tabulated quantity. In form this table is a reversal of Schwarzschild's arrangement (*Astronomische Nachrichten*, Vol. 152, pages 69 to 72) of a tabulation of the same quantities. The values in Table I have all been computed and checked by the present writer. They correct certain discrepancies in

TABLE I. VALUES OF η (OR η') WITH ARGUMENT τ (OR τ').

τ	0.0		0.1		0.2		0.3		0.4		τ
	η	DIFF.	η	DIFF.	η	DIFF.	η	DIFF.	η	DIFF.	
0	00°00		46 60		60°54		71 36		80 93		0
		20 88		1 66		1 17		0 99		0 92	
1	20.88		48.26		61.71		72.35		81.85		1
		5.57		1.58		1.15		0.99		0.91	
2	26.45		49.84		62.86		73.34		82.76		2
		3.96		1.51		1.12		0.97		0.91	
3	30.41		51.35		63.98		74.31		83.67		3
		3.21		1.45		1.11		0.97		0.91	
4	33.62		52.80		65.09		75.28		84.58		4
		2.73		1.39		1.08		0.96		0.91	
5	36.35		54.19		66.17		76.24		85.49		5
		2.42		1.34		1.07		0.95		0.90	
6	38.77		55.53		67.24		77.19		86.39		6
		2.21		1.30		1.05		0.94		0.91	
7	40.98		56.83		68.29		78.13		87.30		7
		2.00		1.27		1.04		0.94		0.90	
8	42.98		58.10		69.33		79.07		88.20		8
		1.87		1.24		1.02		0.93		0.90	
9	44.85		59.34		70.35		80.00		89.10		9
		1.75		1.20		1.01		0.93		0.90	
10	46.60		60.54		71.36		80.93		90.00		10

TABLE II. VALUES OF ω WITH ARGUMENTS, τ AND τ'.

τ' / τ	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	τ' / τ
0.10	180.00	165.85	154.63	144.58	135.00	125.42	115.37	104.15	90.00	0.10
0.20	194.15	180.00	165.85	150.79	135.00	110.21	104.15	90.00	75.85	0.20
0.30	205.37	194.15	180.00	160.33	135.00	109.67	90.00	75.85	64.63	0.30
0.40	215.42	209.21	199.67	180.00	135.00	90.00	70.33	60.79	54.58	0.40
0.50	225.00	225.00	225.00	225.00	CIRCLE	45.00	45.00	45.00	45.00	0.50
0.60	234.58	240.79	250.33	270.00	315.00	0.00	19.67	29.21	35.42	0.60
0.70	244.63	255.85	270.00	289.67	315.00	340.33	0.00	14.15	25.37	0.70
0.80	255.85	270.00	284.15	299.21	315.00	330.79	345.85	0.00	14.15	0.80
0.90	270.00	284.15	295.37	305.42	315.00	324.58	334.63	345.85	0.00	0.90
τ / τ'	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	τ / τ'

Schwarzschild's numbers. In using this table, *when τ (or τ') is greater than 0.500 subtract from unity and take the supplement of the corresponding value of η (or η').*

Since the quantities, ω, e, M_1 and M_3, are functions of τ and τ', tables with τ and τ' as arguments may be constructed from which these quantities may be taken. But in view of the brevity of the process of computation of ω, e, M_1 and M_3 with the aid of Table I and the *Table for the True Anomalies* it is doubtful whether the publication of extensive tables of this kind would be warranted. Such tables would require cross interpolation and would not find very frequent application. Herewith are given brief tables which will serve in some cases to give preliminary values of ω and c and will furnish in all cases a rough check on the computed values.

In the least-square solution, the mean velocity, γ', may be used as an element instead of the velocity of the center of mass of the system. This substitution of γ' for γ removes from the equations of condition the three terms resulting from the differentiation of $Ke \cos \omega$ and shortens the computation appreciably, especially when several hypotheses are needed and the probable error of γ is not determined.

TABLE III. VALUES OF e WITH ARGUMENTS, τ AND τ'.

$\tau \backslash \tau'$	0.10	0.20	0.30	0.40	0.50	τ' / τ
0.10	0.801	0.740	0.709	0.692	0.687	0.10
0.20	0.740	0.624	0.550	0.506	0.492	0.20
0.30	0.709	0.550	0.431	0.350	0.320	0.30
0.40	0.692	0.506	0.350	0.220	0.158	0.40
0.50	0.687	0.492	0.320	0.158	0.000	0.50
τ / τ'	0.10	0.20	0.30	0.40	0.50	$\tau \backslash \tau'$

NOTE: If an argument is greater than 0.50 subtract it from unity before entering Table III.

Referring now to Schlesinger's adaptation (*Allegheny Observatory Publications,* Vol. I, No. 6) of the formulæ of Lehmann-Lilhés, we may introduce the element, γ', if in equations (4) of Schlesinger's paper we substitute for the third of the group with its four terms on the right hand side, the simple relation, $\Gamma' = \delta\gamma'$; and for Γ in equation (5), Γ'.

When the least-square solution is completed the center of mass velocity is derived from the equation,

$$\gamma = \gamma' - K e \cos \omega.$$

Ann Arbor, Mich., January 11, 1916.

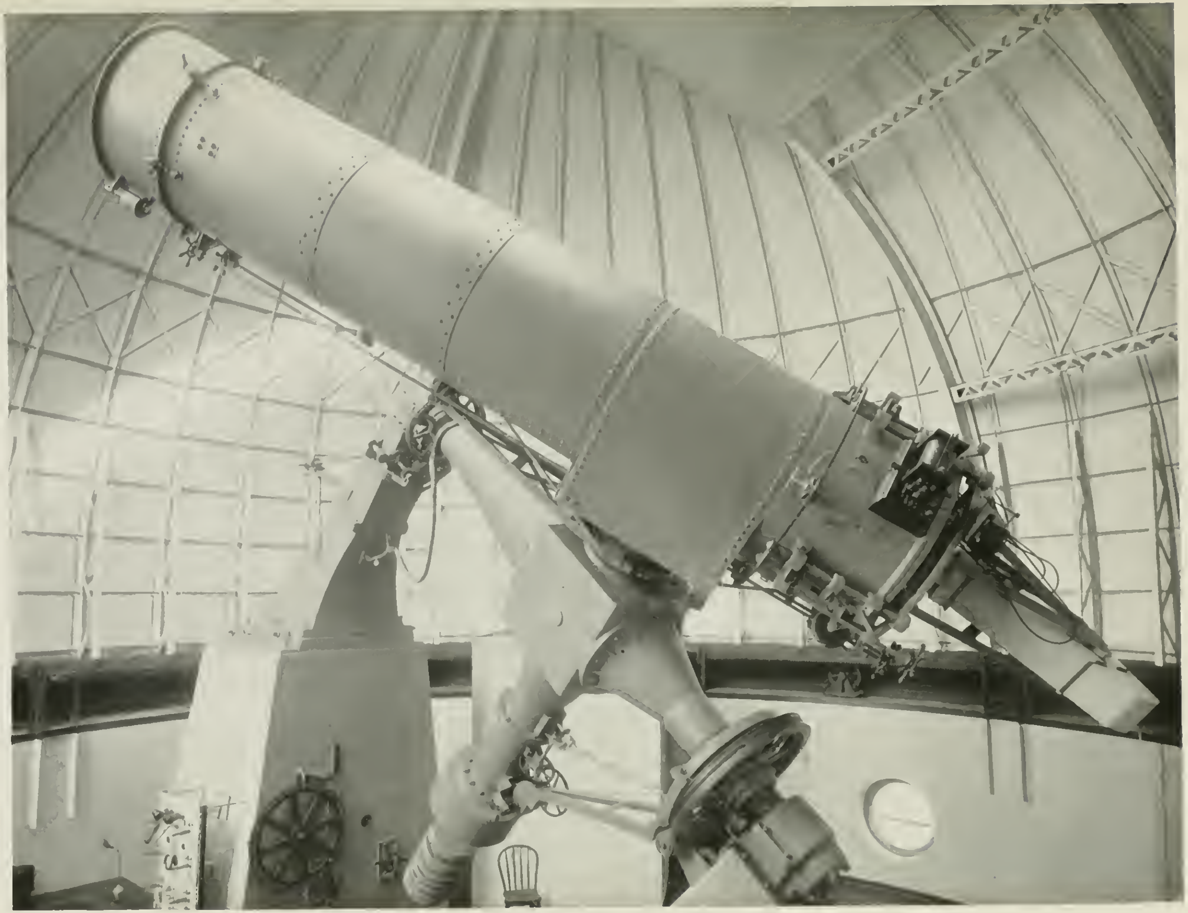

Plate K. The Thirty-seven and One-half Inch Reflecting Telescope

DISCOVERY OF TWO BRIGHT-LINE STARS OF CLASS B

By PAUL W. MERRILL

ν GEMINORUM.

$\alpha = 6^h 23^m.1$; $\delta = +20° 17'$; Mag. = 4.1; Class B5.

A feeble bright Hα line is seen in the spectrum of this star on plates taken on the nights of November 12 and December 3, 1915, apparently being superposed on a broad, weak absorption line. The other hydrogen lines show no distinct bright portions. The star thus belongs to the Electra group[1] of bright-line stars of Class B.

The hydrogen lines other than Hα are rather wide, diffuse absorption lines, but several show a narrow central core, the effect, perhaps, of invisible bright components. Calcium K is present as an absorption line, possibly with bright borders. Several weak absorption lines of helium and other elements are also seen.

This star was found to have a variable radial velocity[2] by the Yerkes Observatory.

β CANIS MINORIS.

$\alpha = 7^h 21^m.7$; $\delta = +8° 29'$; Mag. = 3.1; Class B8.

Photographs taken on December 3 and December 10, 1915, show a bright Hα line in the spectrum of this star, superposed on weak absorption. As the other hydrogen lines are dark it should also be included in the Electra group. Several hydrogen lines show traces of structure similar to that described above for ν Geminorum. Aside from the hydrogen lines the spectrum is nearly continuous.

[1] *Lick Bul.*, 7, 176, 1913.

[2] *Ibid*, 6, 22, 1910.

OBSERVATIONS OF COMET TAYLOR, 1915 *e*

Made at Ann Arbor With the 12¼-inch Refractor

By BERNHARD H. DAWSON

1915 1916	ANN ARBOR M. T.	*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p.\Delta$ FOR α	LOG $p.\Delta$ FOR δ
Dec. 10	$11^h 57^m 35^s$	1	10, 10	$-6^s.63$	$+7' 53''.4$	$5^h 20^m 25^s.87$	$+0° 49' 25''.7$	8.1496n	0.7630
Jan. 7	9 51 7	2	8, 8	−27.93	−6 0.1	5 6 49.73	+10 14 31.7	8.2954n	0.6662
7	10 35 5	2	8, 8	−28.38	−5 12.4	5 6 49.28	+10 15 19.4	8.8130	0.6672
8	10 22 0	3	., 5	.....	−12 0.0	. . ..	+10 40 34.1	......	0.6614
8	10 37 12	3	7, .	+31.63	....	5 6 42.35	.. ..	8.8858	......

MEAN PLACES OF COMPARISON STARS.

*	α 1915.0	RED. TO APP. PL.	δ 1915.0	RED. TO APP. PL.	AUTHORITY.
1	$5^h 20^m 27^s.48$ 1916.0	$+5^s.02$	$+0° 41' 21''.0$ 1916.0	$+11''.2$	A. G. Nicolajew, 1300.
2	5 7 15.52	+2.14	+10 20 25.7	+ 6.1	A. G. Leipzig I, 1547.
3	5 6 8.55	+2.17	+10 52 27.9	+ 6.2	BD + 10°726, connected with *4.
4	5 5 20.14	+2.17	+10 47 12.2	+ 6.2	A. G. Leipzig I, 1535.

*2 was connected with A. G. Leipzig I, 1553, $\Delta\alpha = -40^s.97$, $\Delta\delta = +1' 58''.6$.

Ann Arbor, January, 1916.

NOTE ON REPRODUCTIONS OF SPECTRA IN THIS VOLUME

By RALPH H. CURTISS

The reproductions of spectra in this volume have been made by the writer with a commercial enlarging camera of the usual pattern to which has been attached in place of the original plate holder a special apparatus for widening spectra, designed by the writer and constructed in the Observatory instrument shop by Mr. E. J. Colliau.

This special apparatus for widening spectra employs the clepsydra principle, the fluid element being a high grade of machine oil. A cylinder of commercial brass tubing is mounted with its axis vertical immediately below the plate holder. A brass piston ringed with rawhide fits tightly in the cylinder. Two tubes, leading from the lower to the upper end of the cylinder, form outside connections around the piston, one with a stop-cock for fast motion and the other with a screw valve permitting very slow motion capable of accurate regulation. The piston rod extends upward from the cylinder to the lower side of the plate holder. As the plate holder moves vertically in V-groove guides its weight is carried solely by the piston rod.

The source of light is a pair of nitrogen tungsten lamps with a combined candle power of about four hundred. Two parallel ground glass plates diffuse this light properly before it reaches the subject to be enlarged. The spectrogram is set with the direction of dispersion horizontal, *i. e.,* with the spectrum lines vertical. Near the image plane adjustable diaphragms limit as desired the region to be photographed; and slides of different apertures in the plate holder determine the length and width of the photograph and make it possible to expose star and comparison spectra side by side on the same plate.

When an exposure is to be made, the diaphragms and slides in front of the photographic plate having been properly adjusted, the clepsydra stop-cock is opened and the piston rod with the plate holder resting upon it is raised to its initial position. The stop-cock is closed; the light is turned on and the plate holder is allowed to fall by its own weight and that of the piston rod and piston against the resistance of the clepsydra fluid flowing through the slow motion valve, which must be set in advance for the length of exposure desired. When the exposure is started the attention of the operator is no longer required as the exposure is stopped automatically when the plate holder falls to a certain point.

The apparatus in its present condition, as used in the preparation of the reproductions of spectra in this volume, is avowedly in preliminary form. Antifriction bearings have not been used and the cylinder of ordinary commercial tubing has not been bored. In this state the instrument could not be expected to give perfect results but its performance is satisfactory for many purposes.

The reproductions in the present volume have been enlarged from six to eight fold in length and from 35 to 50 fold in width. The original copies have been made on Seed 23 or Process plates. Negatives were then made on Process plates and from these the prints were made. The spectra of each set were brought to the same scale by altering the image distance in the enlarging camera, though this reduction to identical scale was not accurately possible for two spectra, the one made with the first prism used in our spectrograph and the other made with the prism now in use. Also interesting difficulties were encountered in bringing spectra made with the same prism into exact linear correspondence because of scale variations arising in the same or different papers after printing.

PLATE C.

The spectra of γ Cassiopeiæ and β Monocerotis with titanium comparison show interesting types of emission lines both of hydrogen and of the metals. The central reversals of the hydro-

gen lines develop strongly in β Monocerotis whereas in γ Cassiopeiæ the broad absorption borders of these lines are relatively strong. The variation of these features from line to line may be observed in accordance with published descriptions except in the case of the $H\beta$ line in γ Cassiopeiæ's spectrum. This line is abnormally weak because the original was made on a lantern slide plate which was not sensitive in this region. Absorption lines, especially of helium, are brought out.

PLATE D.

This plate reproduces five spectrograms of f[1] Cygni exhibiting the progressive increase in the intensity of hydrogen absorption with the lapse of time, together with a change of structure most clearly seen in the case of $H\beta$. The other absorption lines, mainly due to helium, show little or no changes in intensity. In the fourth photograph two relatively sharp absorption lines near $H\delta$ are easily recognized as spurious features due to pin holes in the original negative.

PLATE E.

These two spectra of H. R. 985, the one made in 1912 and the other in 1916, bring out changes in the structure of the hydrogen lines in the interval of four years. The emission is stronger to the right of the central absorption of $H\delta$, $H\gamma$ and $H\beta$ in 1912 and to the left in 1916. No certain change is noted in the helium lines, which are very broad and diffuse as in f[1] Cygni.

PLATE F.

In order to permit of a scale of enlargement not too small and to adapt the exposure time to the different densities in its different parts the spectrum of *o* Ceti has been reproduced in two overlapping sections. The second section is not strongly exposed in the original and hence strong contrast could not be expected in the copy. The weakness of G, the strength of g and the absence of $H\epsilon$ in the series of bright hydrogen lines are notable features. The spectra of S Hydræe and W Lyræ were enlarged without widening and were reproduced in parallel in order to show the range of displacement of $H\delta$ and $H\gamma$ emission lines in two different stars.

PLATES G AND H.

These plates include our best photographs of spectra of Class R compared with the spectrum of the Sun (Class G) and α Arietis (Class K2) on the one side and with several Class N spectra on the other. The spectrum of U Hydræ at the end of the series is known as the standard of Class N. The series has been arranged as nearly as could be judged in the order of development from the solar type to Type IV. In this series the spectra of Class R supply graded steps in the transition from Class G to Class N with some overlapping of late R and early N spectra. The arrangement in order of development is based largely on the increasing absorption in the region of shorter wave-length partly due to increased general absorption in this region and partly to strengthening of the absorption of Cyanogen Group III beginning at λ 4216 and partly to Group V of the Swan spectrum. In the copies it was intended to preserve the intensity ratios of the same regions on the different original plates and to bring all plates to a similar degree of contrast. Obviously the actual intensity curve of an original plate is an accidental effect due to the combined influence of many factors aside from the real distribution of energy in the star's light before it enters the earth's atmosphere. But comparison among different plates made with the same apparatus is of the greatest value. On the different negatives in the first half of the series the strength of the region bordering the carbon band near λ 4700 on the side of greater wave-length was kept at nearly uniform density but in the second half this region was made less dark in order that the interesting region on either side might not be printed out.

The average strengthening of the carbon bands at and near λ 4700 down the series was a criterion also employed in arranging these spectra in order of probable evolution though notable variations from this rule are evident.

The weakening of some lines and the strengthening of others down the series were also kept in mind. . These changes, which are brought out quantitatively in Doctor Rufus's tables, are very interesting and in some cases very conspicuous. Among such changes may be mentioned the strengthening in Class R of a line near λ 4224 very close to the g line on the side of shorter wave-length, and the weakening of Hδ, Hγ and Hβ. Doctor Rufus refers especially to the variations in the group of lines near Hβ on the side of greater wave-length. These variations may be followed down the entire series. Of these lines λ 4958 is designated on Plates G and H. The lines used by Adams and Kohlschütter to determine spectral class by comparison with Hγ and Hβ may be identified easily on the reproductions though in every case they are blended more or less with close lines. λ 4326 and λ 4352 are the first well defined lines on either side of Hγ. λ 4872 is the first line visible to the right of Hβ. λ 4405 and λ 4958 are indicated. In the sun Hγ is blended with a close line of shorter wave-length from which it is resolved in α Arietis. Of the lines which Adams and Kohlschütter found strong in high luminosity stars of Class K, λ 4216 is at or near the head of a cyanogen band in Class R, λ 4395 is the second line to the left of λ 4405 and λ 4408 is the first line to the right of λ 4405. λ's 4395 and 4408 are not especially strong in spectra of Class R.

The interesting divergence of the spectrum of B. D. — 10°.5057 from the general type of other members of Class R is obvious in Plate G. Hγ, Hβ and G are absent or weak in this spectrum.

PLATE I

This plate is intended to bring out the important steps in the transition from the solar spectrum to that of a standard Class N star. For this purpose selections have been made from the spectra in Plates G and H.

PLATE J

This plate furnishes a comparison of the solar spectrum with the "earliest" Class R spectrum in Plates G and I. Both of these copies have been shaded to show the spectral features to the H line and have been reproduced on a scale somewhat greater than that of Plates G and H. The spectrum of the titanium spark at the top establishes wave-lengths for the identification of faint lines. The spectrum of an "early" Class N star is added for comparison at the bottom.

The spectra in Plates G, H, I and J support very clearly Doctor Rufus' conclusion that spectra of Class R form the connecting links between Class N and the solar spectrum.

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END OF VOLUME.

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